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OPTIMAL POWER FLOW IN ISLANDED MICROGRIDS

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LIST OF SYMBOLS AND ABBREVIATIONS

Pollutants symbols

Abbreviations - Glossary

MG	Microgrid
OPF	Optimal Power Flow
DMS	Distribution Management Systems
AC	Alternative Current
GSO	Glow-worm Swarm Optimization
DG	Distributed Generator
PU	Per Unit
IEEE	Institute for Electrical and Electronics Engineers
LV	Low Voltage
OF	Objective Function

CHAPTER I. INTRODUCTION

1. BACKGROUND AND MOTIVATION

According to the Department Of Energy of the United States, Microgrids, MGs can be defined as “localized grids that can disconnect from the traditional grid to operate autonomously and help mitigate grid disturbances to strengthen grid resilience…” they “… can play an important role in transforming the nation’s electric grid”… “MGs also support a flexible and efficient electric grid, by enabling the integration of growing deployments of renewable sources of energy such as solar and wind and distributed energy resources such as combined heat and power, energy storage, and demand response.”

Renewable sources of energy are typically inverter-interfaced units showing low inertia and causing regulation problems in power systems. More recently, the advent of new architectures for the electrical energy distribution such as MGs, with a large penetration of energy generated from Renewable Sources and many inverter interfaced units poses the problem of solving the Optimal Power Flow, OPF, in small islanded power systems, in which generated power of generator and loads depend on frequency and voltage. And a formulation of the problem should also account for the presence of inverter-interfaced units with control laws specifically designed to contrast voltage and frequency deviations when a sudden load variation occurs.

OPF in electrical power systems is the problem of identifying the optimal dispatch of generation sources to get technical and economical issues. The problem is typically solved in Distribution Management Systems, DMS, which implement the highest level of the hierarchy of controllers within MGs [1]. They take care of control functions such as optimized real and reactive power dispatch, voltage regulation, contingency analysis, capability maximization, or reconfiguration.

In MGs, a three levels control hierarchical architecture [1] allows to provide good power quality. The meaning of three levels could be explained as below (see figure 1):

- Level 1, primary control: In this level, they usually use droop-control method to simulate physical behaviors that makes the system stable and more damped.

- Level 2, secondary control: Ensures that the electrical levels into the MG are within the required values and controls the seamless connection or disconnection between MG and distribution system.
- Level 3, tertiary control: Controls the power flow in the MG and between the MG and the grid.

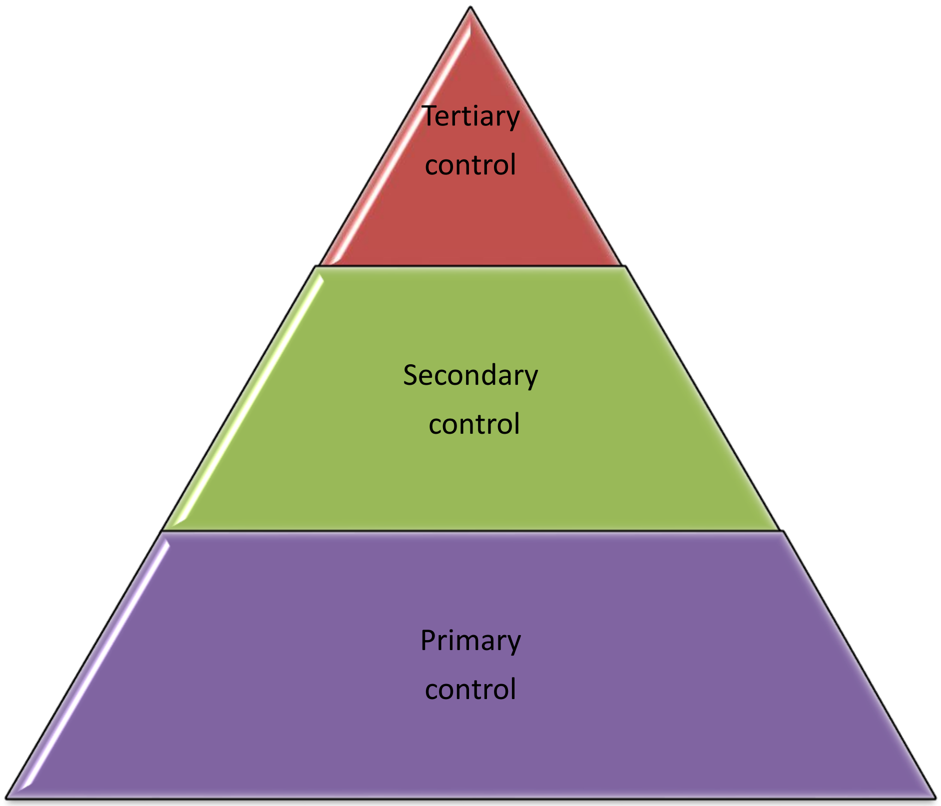

Figure 1 - Hierarchical control levels of an MG

Droop control is used to mimic the behavior of a synchronous generator, it is based on the well-known P/Q droop method:

$$\omega = \omega^* - GP(s).(P - P^*) \qquad (1)$$

$$E = E^* - GQ(s).(Q - Q^*) \qquad (2)$$

where ω and E are the frequency and amplitude of the output voltage reference, ω^* and E^* are their references, P and Q are the active and reactive power, P^* and Q^* are their references, and $GP(s)$ and $GQ(s)$ are their corresponding transfer functions and could be considered as droop coefficients.

By controlling the droop coefficients, we could control the power of distributed generators, DGs, and the load flow in MGs. It would be very interesting to perform an optimization using the droop coefficients as optimization variables to find values of these coefficients that not only ensure minimum of power losses in MGs but also satisfy the conditions of control levels. In secondary control as mentioned above, it needs a specific period to complete its function. It is the time in which the differenct regulation levels could take place.

OPF is essentially a tertiary level optimal operation issue in electric power systems and the latter has been a long time a concern of many researchers. For this purpose, many optimization techniques have been used, such as “the steepest descent” method [2], particle swarm optimization method [3], fuzzy rules method [4], [5], dynamic programming [6], global optimization [7], [8] and so forth. In addition, optimization problems have been solved considering the presence of energy storage systems, which are critical in islanded MGs systems [5], [8], [9-13]. In [14], a methodology for unbalanced three-phase OPF for DMSs in a smart grid is presented.

In the above mentioned research works, the OPF for three-phase balanced and unbalanced MGs is formulated considering the real powers injected from generators as variables. However, to the best knowledge of the author, there is no study concerning OPF in islanded MGs where generated and consumption powers depend on frequency and voltage levels and operating frequency is constrained as well. Such level of detail is instead required since in islanded MG systems none of the generators can take the role of slack bus and the balance between generated and consumed power should be considered as strictly precise.

More recently, in [3], Particle Swarm Optimization is used to choose the droop parameters and then perform the load flow analysis using the formulation seen in [15]. In the paper, however, the OPF is not dealt with the three phase load flow formulation in which loads and generators depend on voltage and frequency.

In [16], it is shown that with P/V droop control, the DG units that are located electrically far from the load centers automatically deliver a lower share of the power. This automatic power-sharing modification can lead to decreased line losses; therefore, the system shows an overall improved efficiency as compared to the methods focusing on perfect power sharing. Such concept of unequal power sharing is developed in this paper, where droops are optimized based on global objectives such as power losses, the latter being an optimization objective that seems concurrent with dynamic stability of the system.

2. OUTLINE OF THE THESIS

In this thesis, studies about OPF in islanded MGs have been carried out. First, an original formulation and solution approach for the OPF problem in islanded distribution systems is proposed. The methodology is well suited for AC microgrids and can be envisioned as a new hierarchical control structure comprising only two levels: primary and tertiary regulation, the latter also providing iso-frequency operating points for all units and optimized droop parameters for primary regulation. The OPF provides a minimum losses operating point for which voltage drops are limited and power sharing is carried out according to the most adequate physical properties of the infrastructure thus giving rise to increased lifetime of lines and components. Due to the fact that the solution method is based on a numerical approach, the OPF is quite fast and efficient and the operating point can be calculated in times that are comparable to the current secondary regulation level times. Two test systems, 6_bus and 38_bus, have been used. In the different applications. Different scenarios have been investigated to show:

- the possibility to solve the OPF in islanded MGs
- the possible link between stability of operation and minimum losses.

In particular two methods for OPF have been investigated, one based on a numerical approach (Lagrange method) and one based on heuristic optimization (Glow-worm Swarm Optimization, GSO). The latter is a global optimizer that is able to identify multiple optima.Positive and negative aspects of both methods are put into evidence. Numerical optimization indeed can provide stable solutions but cannot deal with a comprehensive formulation able to optimize both active power-to-frequency and reactive power-to-voltage droop coefficient. Also the load with the numerical approach can only be balanced while heuristic optimization allows both balanced and unbalanced loading conditions. Also constraints can be easily considered using a heuristic formulation, while this is not possible using the numerical approach.

The thesis is divided as follow:

- In the first chapter, the motivation and scientific goals of the thesis have been presented.
- In the second chapter, a parametric study changing coefficients of droop control is carried out solving the power flow for balanced and unbalanced three phase different microgrids systems using the Trust Region Method.
- In the third chapter, an original formulation and solution approach for the OPF problem in islanded distribution systems based on Lagrange method is proposed.
- In the fourth chapter applications of GSO method to solve the optimal power flow problem taking into account the constraints of frequency and line ampacity in three-phase islanded Microgrids with variables are both Kgs and Kds are proposed.

The details of optimal results and load flow calculation results are shown in the appendix.

CHAPTER II. LOAD FLOW IN THREE PHASE ISLANDED MICROGRIDS WITH INVERTER INTERFACED UNITS

1. INTRODUCTION

According to traditional load flow method, a slack bus is used to account for an infinite bus capable of holding the system frequency and its local bus voltage constant; the slack bus is also called balanced bus. This method is not suitable for islanded MGs having small and comparable capacity generators; no generator can indeed be physically regarded as a slack bus. In order to face the problem above, inverter interfaced generation units are modeled using the control law used for primary voltage and frequency regulation and a power flow calculation method without a slack bus has been recently studied. In this formulation, both generators and loads have to be considered with power depending on voltage and frequency. A model not accounting for such dependency indeed may lead to inconsistent and misleading results about loss reduction and other subsequent calculation.

The work in [15] proposed a power flow calculation method for islanded power networks. In this paper, the authors proposed a calculation method without slack bus. However, the loads in this study only depend on voltage, not on frequency and the application is devoted to balanced transmission systems. Therefore the proposed model is not suitable for power flow calculations in MGs, which typically show unbalanced loads.

The power flow formulation in three phase unbalanced MGs with voltage and frequency dependent load modeling and the small and comparablw sizes of DGs may causes trouble with traditional methods, such as the Newton Raphson method, due to the lack of the DG that could take a role as slack bus, which has an in finite capable of holding the system frequency and its local bus voltage constant, and the presence of nonlinear algebraic equations.

Authors in [17] propose a new method that can solve this problem: the Newton Trust Region Method. The method is designed by a combination of Newton Raphson Method and Trust Region Method. The paper shows that this new method is a helpful tool to perform accurate steady state studies of islanded MGs and the solution for a 25_bus test system is achieved after a few iterations.

In this chapter, the solution of the power flow for unbalanced three phase microgrids systems using Trust Region Method is used to perform first a parametric study. The speed of this solution is not as quick as the one in [17] (the solution is achieved after a few more iterations with the same test system), but the aim of this study is primarily to show that it is possible to obtain improved quality results (lower power losses) if the primary regulators parameters are modified. Therefore, by means of the Trust Region Method, many extensive power flow calculations have been carried out with different regulators parameters, giving rise to different values of the power losses. Of course, since flows are affected such regulation allows the attainment of other operational objectives connected to the power flows distribution.

In the applications section, the power flow in the 25_bus test system has been thus carried out with many scenarios to show how the power losses term varies as the regulators parameters vary as well, therefore showing that these are sensitive parameters that could have an important role in optimal management of such systems.

2. MODELING OF 3 PHASE ISLANDED MICROGRIDS WITH INVERTER INTERFACED UNITS

2.1. LINES MODELING

Line modeling [17] in this study is based on the dependency on frequency of lines reactance. Carson’s equations are used for a three phase grounded four wire system. With a grid that is well grounded, reactance between the neutral potentials and the ground is assumed to be zero. Applying the Kron’s reduction [18] to the impedance matrix modeling the electromagnetic couplings between conductors and the ground, the following compact matrix formulation can be attained, please see figure 2 where superscript –n has been omitted:

$$\left[Z_{ij}^{abc}\right] = \begin{bmatrix} Z_{ij}^{aa-n} & Z_{ij}^{ab-n} & Z_{ij}^{ac-n} \\ Z_{ij}^{ba-n} & Z_{ij}^{bb-n} & Z_{ij}^{bc-n} \\ Z_{ij}^{ca-n} & Z_{ij}^{cb-n} & Z_{ij}^{cc-n} \end{bmatrix} \quad (3)$$

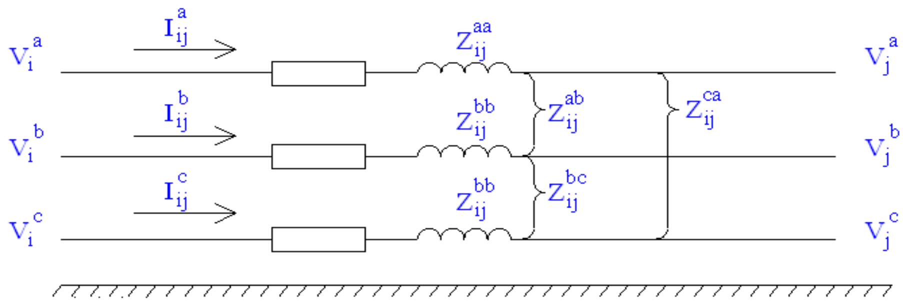

Figure 2 - Model of three phase line

2.2. LOADS MODELING

The frequency and voltage dependency of the power supplied to the loads can be represented as follows:

$$P_{Li} = P_{0i}|V_i|^{\alpha}\left(1 + K_{pf}\Delta f\right) \quad (4)$$

$$Q_{Li} = Q_{0i}|V_i|^{\beta}(1 + K_{qf}\Delta f) \quad (5)$$

where P_{0i} and Q_{0i} are the rated real and reactive power at the operating points respectively; α and β are the coefficients of real and reactive power. The values of α and β are given in [19]. Δf is the frequency deviation (f-f_0); K_{pf} takes the value from 0 to 3.0, and K_{qf} takes the value from -2.0 to 0 [20].

2.3. DISTRIBUTED GENERATORS MODELING

The three phase real and reactive power generated from a DG unit with droop inverter interfaced generation can be expressed by the follow equations:

$$P_{Gri} = -K_{Gi}(f - f_{0i}) \qquad (6)$$

$$Q_{Gri} = -K_{di}(|V_i| - V_{0i}) \qquad (7)$$

In these equations, the coefficients K_{Gi} and K_{di} as well as V_{0i} and f_{0i} characterize the droop regulators of distributed generators. The three phase real and reactive power generated from a PQ_generator can be expressed by the follow equations:

$$P_{PQi} = P_{PQispec} \qquad (8)$$

$$Q_{PQi} = Q_{PQispec} \qquad (9)$$

Where $P_{PQispec}$ and $Q_{PQispec}$ are the pre-specified active and reactive generated of the i-th PQ_generator.

2.4. GENERAL FORMULATION OF THREE PHASE POWER FLOW PROBLEM

2.4.1. FORMULATIONS

For each type of bus (such as PQ bus, PV bus or Droop-bus), we will have the different mismatch equations describing [17]. In this work, we assume that all buses are either droop-buses or PQ bus. For each PQ-Bus, we have mismatch quations as follow:

$$\begin{cases} P_{PQi,spec}^{a,b,c} = P_{Li}^{a,b,c}\left(f,\left|V_i^{a,b,c}\right|\right) \\ \qquad +P_i^{a,b,c}\left(f,\left|V_i^{a,b,c}\right|,\left|V_j^{a,b,c}\right|,\delta_i^{a,b,c},\delta_j^{a,b,c}\right) & (10) \\ Q_{PQi,spec}^{a,b,c} = Q_{Li}^{a,b,c}\left(f,\left|V_i^{a,b,c}\right|\right) \\ \qquad +Q_i^{a,b,c}\left(f,\left|V_i^{a,b,c}\right|,\left|V_j^{a,b,c}\right|,\delta_i^{a,b,c},\delta_j^{a,b,c}\right) & (11) \end{cases}$$

where

$P_{PQi,spec}^{a,b,c}$ and $Q_{PQi,spec}^{a,b,c}$ are the pre-specified active and reactive power at each phases of PQ-Bus i.

$V_i^{a,b,c}$ is the voltage of each phase at bus i

$\delta_i^{a,b,c}$ is the angle voltage of each phase at bus i

$P_{Li}^{a,b,c}$ and $Q_{Li}^{a,b,c}$ are the active and reactive load power at each phases of bus i

$P_i^{a,b,c}$ and $Q_i^{a,b,c}$ are the active and reactive power injected to the grid at each phases of bus i, can be attained, as follows:

$$P_i^a = \sum_{\substack{j=1 \\ j\neq i}}^{n_{br}} \sum_{ph=a,b,c} \begin{bmatrix} |V_i^a|\left|Y_{ij}^{a(ph)-n}\right|\left|V_i^{(ph)}\right|\cos\left(\theta_{ij}^{a(ph)}+\delta_i^{(ph)}-\delta_i^a\right) \\ -|V_i^a|\left|Y_{ij}^{a(ph-n)}\right|\left|V_j^{(ph)}\right|\cos\left(\theta_{ij}^{a(ph)}+\delta_j^{(ph)}-\delta_i^a\right) \end{bmatrix} \quad (12)$$

$$Q_i^a = \sum_{\substack{j=1 \\ j\neq i}}^{n_{br}} \sum_{ph=a,b,c} \begin{bmatrix} |V_i^a|\left|Y_{ij}^{a(ph)-n}\right|\left|V_j^{(ph)}\right|\sin\left(\theta_{ij}^{a(ph)}+\delta_i^{(ph)}-\delta_i^a\right) \\ -|V_i^a|\left|Y_{ij}^{a(ph-n)}\right|\left|V_i^{(ph)}\right|\sin\left(\theta_{ij}^{a(ph)}+\delta_i^{(ph)}-\delta_i^a\right) \end{bmatrix} \quad (13)$$

where $Y_{ij}^{a(ph)-n}$ is the branch admittance between two nodes i and j

Similar equations can be extracted for phase b and phase c.

For each PQ-Bus i, we have the unknown variables:

$$x_{PQi} = \left[\delta_i^{a,b,c} \middle| V_i^{a,b,c} \middle|\right]^T \qquad (14)$$

For all PQ-Bus, we have the unknown variables:

$$x_{PQ} = \left[x_{PQ1} \dots x_{PQn_{pq}}\right]^T \qquad (15)$$

where n_{pq} is the number of PQ-Bus.

For each of the droop-buses, i, we have mismatch equations as follow:

$$\begin{cases} 0 = P_{Li}^{a,b,c}\left(f, \left|V_i^{a,b,c}\right|\right) - P_{Gi}^{a,b,c} \\ \quad +P_i^{a,b,c}\left(f, \left|V_i^{a,b,c}\right|, \left|V_j^{a,b,c}\right|, \delta_i^{a,b,c}, \delta_j^{a,b,c}\right) & (16) \\ 0 = Q_{Li}^{a,b,c}\left(f, \left|V_i^{a,b,c}\right|\right) - Q_{Gi}^{a,b,c} \\ \quad +Q_i^{a,b,c}\left(f, \left|V_i^{a,b,c}\right|, \left|V_j^{a,b,c}\right|, \delta_i^{a,b,c}, \delta_j^{a,b,c}\right) & (17) \\ 0 = |V_i^a| - \left|V_i^b\right| & (18) \\ 0 = |V_i^a| - |V_i^c| & (19) \\ 0 = \delta_i^a - \delta_i^b - \left(\frac{2\pi}{3}\right) & (20) \\ 0 = \delta_i^a - \delta_i^b + \left(\frac{2\pi}{3}\right) & (21) \\ 0 = P_{Gi}^a + P_{Gi}^b + P_{Gi}^c - P_{Gi}(f) & (22) \\ 0 = Q_{Gi}^a + Q_{Gi}^b + Q_{Gi}^c - Q_{Gi}\left(\left|V_i^{a,b,c}\right|\right) & (23) \end{cases}$$

For each Droop-bus i, we have the unknown variables:

$$x_{Di} = \left[\delta_i^{a,b,c} \middle| V_i^{a,b,c} \middle| P_{Gi}^{a,b,c} Q_{Gi}^{a,b,c}\right]^T \qquad (24)$$

For all Droop-bus, we have the unknown variables:

$$x_D = \left[x_{D1} \dots x_{Dn_d}\right]^T \qquad (25)$$

where n_d is the number of Droop-bus.

So we have the total number of mismatch equations, n, and their corresponding unknown variables X:

$$n = 12 \times n_d + 6 \times n_{pq} \qquad (26)$$

$$X = \left[x_D x_{pq} f\right] \qquad (27)$$

The mismatch equations are nonlinear algebraic equations. The Trust region method is a robust method to solve such problems. Using the function "fsolve" of Matlab which uses the Trust region method, we can obtain the unbalanced three phase power flow solution.

Using the load flow problem formulation, in this chapter, parametric studies on an islanded 25_bus test system, whose parameters are taken from [21], have been carried out. The load flow problem has been solved using the methodology proposed above. As expected, the results show that there are many different sets of parameters satisfying the condition f = 50Hz, while power losses change. Changing the droop parameters produces a change of the power loss in the system. With f within the admissible range, the set of parameters satisfying the condition of minimum losses power sharing can thus be chosen.

2.4.2. SOLUTION METHOD

The mismatch equations are nonlinear algebraic equations. Function "fsolve" of Matlab is a robust tool to solve this problem. Using "fsolve" which is based on the Trust region method, we can obtain the balanced and unbalanced three phase power flow solution. In "fsolve", we have two algorithms to choose to solve the problem: "trust-region-dogleg" and "trust-region-reflective. In general, the pseudo-code of these algorithms are the same but the way to update trust region size is diferent. The pseudocode of the solution method is shown in figure 3 below.

Step 1: *Given* X_0; $\varepsilon \geq 0$; , $r_{kmax} > 0$; $r_{k0} \in [0, r_{kmax}]$*; k=0;*
Step 2: *if* $F_{i(X_k)} \leq \varepsilon$ *then Stop;*
else then calculate Δk*;*
Step 3 *(update trust region size): depend on chosen algorithms, a comparison ratio* μ *is calculated and then* X_{k+1} *and* r_{k+1} *are updated;*
Step 4: $k = k + 1$*; go to* ***Step 2****.*

Figure 3 - Pseudocode of "fsolve"

3. APPLICATIONS

The load flow problem for an islanded system has been followed using the methodology proposed above. In this section, the results of load flow on three phases balanced and unbalanced test systems are shown. In all application cases, bus#1 is taken as reference for displacements ($\delta_i^a = 0$) and coefficients of loads K_{pf}, K_{qf} take the value 1.

3.1. THREE PHASE BALANCED TEST SYSTEM

The applications of proposed method on 6_bus, 16_bus and 38_bus test system are shown in this section and in all of applications, we assume that all of Generators are droop-buses and loads depend on voltages.

3.1.1. 6_BUS BALANCED TEST SYSTEM

Figure 4 shows the 6_bus balanced test system. As shown in the figure 4, three DG units have been placed at buses 1, 2, and 3, respectively. The line-data and bus-data are shown in Table I and Table II corresponding in *I.1 Chapter 2* of appendix.

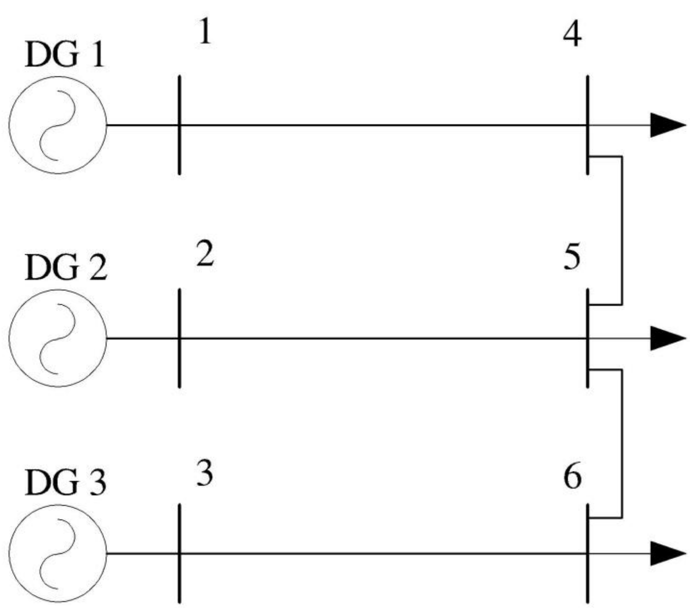

Figure 4 - 6_bus balanced test system

Voltage profile and loads results of the proposed power flow method on 6_bus balanced system are shown in table I.

TABLE II. RESULT OF LOAD FLOW ON 6_BUS BALANCED SYSTEM, PU

Bus	**Vi**	**di**	**PGi**	**Qgi**	**PLi**	**QLi**
1	0.9871	0.0000	0.5825	0.3563	0.0000	0.0000
2	0.9793	-0.0075	0.4960	0.5724	0.0000	0.0000
3	0.9957	0.0303	0.7847	0.1177	0.0000	0.0000
4	0.9447	0.0061	0.0000	0.0000	0.7040	0.4017
5	0.9499	0.0062	0.0000	0.0000	0.3920	0.2026
6	0.9482	0.0166	0.0000	0.0000	0.6775	0.4021
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	1.8631	1.0465	1.7735	1.0064	0.9984	0.0896

Where Vi, di, PGi, Qgi, PLi, Qli are magnitude of voltage, voltage angle, generated real power, generated reactive power, real power of load, reactive power of load at bus i respectively; PG and QG are total generated real power, total generated reactive power, total real power of loads, reactive power of loads in system respectively; f is frequency of system; Ploss is total real power loss of system.

3.1.2. 16_BUS BALANCED TEST SYSTEM

Figure 5 shows the 16_bus balanced test system. In the figure 5, three DG units have been placed at buses 1, 2, and 3, respectively. The line-data and bus-data are shown in Table III and Table IV corresponding in *I.1 Chapter 2* of appendix.

Voltage profile and loads results of the proposed power flow method on 16_bus balanced system are shown in table II.

TABLE III. RESULT OF LOAD FLOW ON 16_BUS BALANCED SYSTEM, PU

Bus	**Vi**	**di**	**PGi**	**Qgi**	**PLi**	**QLi**
1	0.9963	0.0000	0.5177	0.2193	0.0000	0.0000
2	0.9932	-0.0062	0.2658	0.4093	0.0000	0.0000
3	0.9922	0.0003	1.0330	0.2337	0.0000	0.0000
4	0.9871	-0.0038	0.0000	0.0000	0.0585	0.0195
5	0.9833	-0.0044	0.0000	0.0000	0.1934	0.0967
6	0.9811	-0.0046	0.0000	0.0000	0.1925	0.0963
7	0.9811	-0.0046	0.0000	0.0000	0.0433	0.0289
8	0.9871	-0.0039	0.0000	0.0000	0.0585	0.0341
9	0.9868	-0.0041	0.0000	0.0000	0.0584	0.0195
10	0.9875	-0.0037	0.0000	0.0000	0.0585	0.0195
11	0.9882	-0.0045	0.0000	0.0000	0.1172	0.0781
12	0.9880	-0.0045	0.0000	0.0000	0.0586	0.0098
13	0.9911	-0.0058	0.0000	0.0000	0.0589	0.0196
14	0.9876	-0.0028	0.0000	0.0000	0.0878	0.0390
15	0.9850	-0.0034	0.0000	0.0000	0.4075	0.1940
16	0.9882	-0.0023	0.0000	0.0000	0.4102	0.1953
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	1.8164	0.8624	1.8032	0.8503	0.9991	0.0132

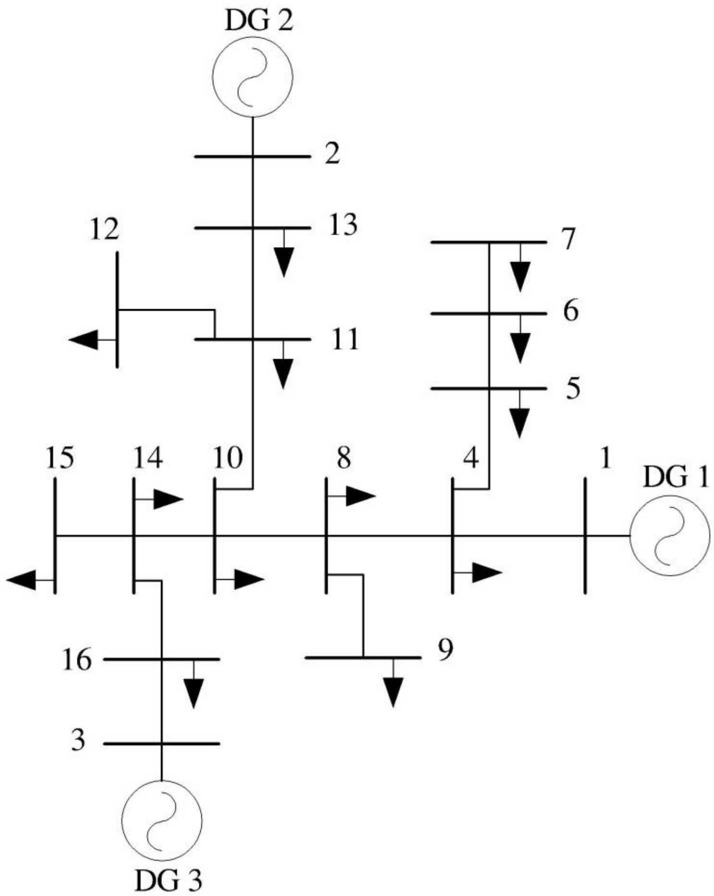

Figure 5 - 16_bus balanced test system

3.1.3. 38_BUS BALANCED TEST SYSTEM

Figure 6 shows the 38_bus balanced test system. In the figure 6, five DG units have been placed at buses 1, 2, 3, 4 and 5 respectively. The line-data and bus-data are shown in Table V and Table VI corresponding in *I.1 Chapter 2* of appendix.

Voltage profile and loads results of the proposed power flow method on 38_bus balanced system are shown in table III.

TABLE IV. RESULT OF LOAD FLOW ON 38_BUS BALANCED SYSTEM, PU

Bus	**Vi**	**di**	**PGi**	**Qgi**	**PLi**	**QLi**
1	1.0052	0.0000	1.0295	0.2875	0.0000	0.0000

Bus	Vi	di	PGi	Qgi	PLi	QLi
2	0.9945	-0.0011	0.7682	0.4663	0.0000	0.0000
3	0.9946	-0.0150	0.5592	0.4615	0.0000	0.0000
4	0.9955	-0.0108	0.5592	0.2901	0.0000	0.0000
5	0.9926	-0.0189	0.7682	0.6949	0.0000	0.0000
6	0.9831	-0.0148	0.0000	0.0000	0.0000	0.0000
7	0.9853	-0.0088	0.0000	0.0000	0.1951	0.0953
8	0.9889	-0.0093	0.0000	0.0000	0.1962	0.0965
9	0.9890	-0.0109	0.0000	0.0000	0.0597	0.0188
10	0.9895	-0.0123	0.0000	0.0000	0.0589	0.0193
11	0.9896	-0.0126	0.0000	0.0000	0.0442	0.0290
12	0.9899	-0.0131	0.0000	0.0000	0.0593	0.0337
13	0.9891	-0.0165	0.0000	0.0000	0.0589	0.0338
14	0.9871	-0.0177	0.0000	0.0000	0.1183	0.0761
15	0.9858	-0.0183	0.0000	0.0000	0.0586	0.0095
16	0.9846	-0.0186	0.0000	0.0000	0.0597	0.0183
17	0.9828	-0.0198	0.0000	0.0000	0.0583	0.0189
18	0.9822	-0.0200	0.0000	0.0000	0.0895	0.0360
19	0.9835	-0.0147	0.0000	0.0000	0.0884	0.0375
20	0.9877	-0.0139	0.0000	0.0000	0.0881	0.0384
21	0.9893	-0.0133	0.0000	0.0000	0.0896	0.0376
22	0.9928	-0.0116	0.0000	0.0000	0.0892	0.0390
23	0.9828	-0.0158	0.0000	0.0000	0.0874	0.0473
24	0.9838	-0.0178	0.0000	0.0000	0.4087	0.1897

Bus	Vi	di	PGi	Qgi	PLi	QLi
25	0.9880	-0.0191	0.0000	0.0000	0.4114	0.1925
26	0.9832	-0.0101	0.0000	0.0000	0.0583	0.0237
27	0.9827	-0.0094	0.0000	0.0000	0.0597	0.0226
28	0.9804	-0.0070	0.0000	0.0000	0.0581	0.0187
29	0.9790	-0.0050	0.0000	0.0000	0.1159	0.0653
30	0.9758	-0.0035	0.0000	0.0000	0.1922	0.5536
31	0.9721	-0.0049	0.0000	0.0000	0.1458	0.0626
32	0.9713	-0.0053	0.0000	0.0000	0.2039	0.0891
33	0.9711	-0.0054	0.0000	0.0000	0.0572	0.0363
34	0.9837	-0.0105	0.0000	0.0000	0.0597	0.0182
35	0.9831	-0.0148	0.0000	0.0000	0.0982	0.0562
36	0.9827	-0.0147	0.0000	0.0000	0.0895	0.0361
37	0.9826	-0.0139	0.0000	0.0000	0.1166	0.0756
38	0.9830	-0.0130	0.0000	0.0000	0.0589	0.0281
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	3.6844	2.2003	3.6332	2.1532	0.9974	0.0512

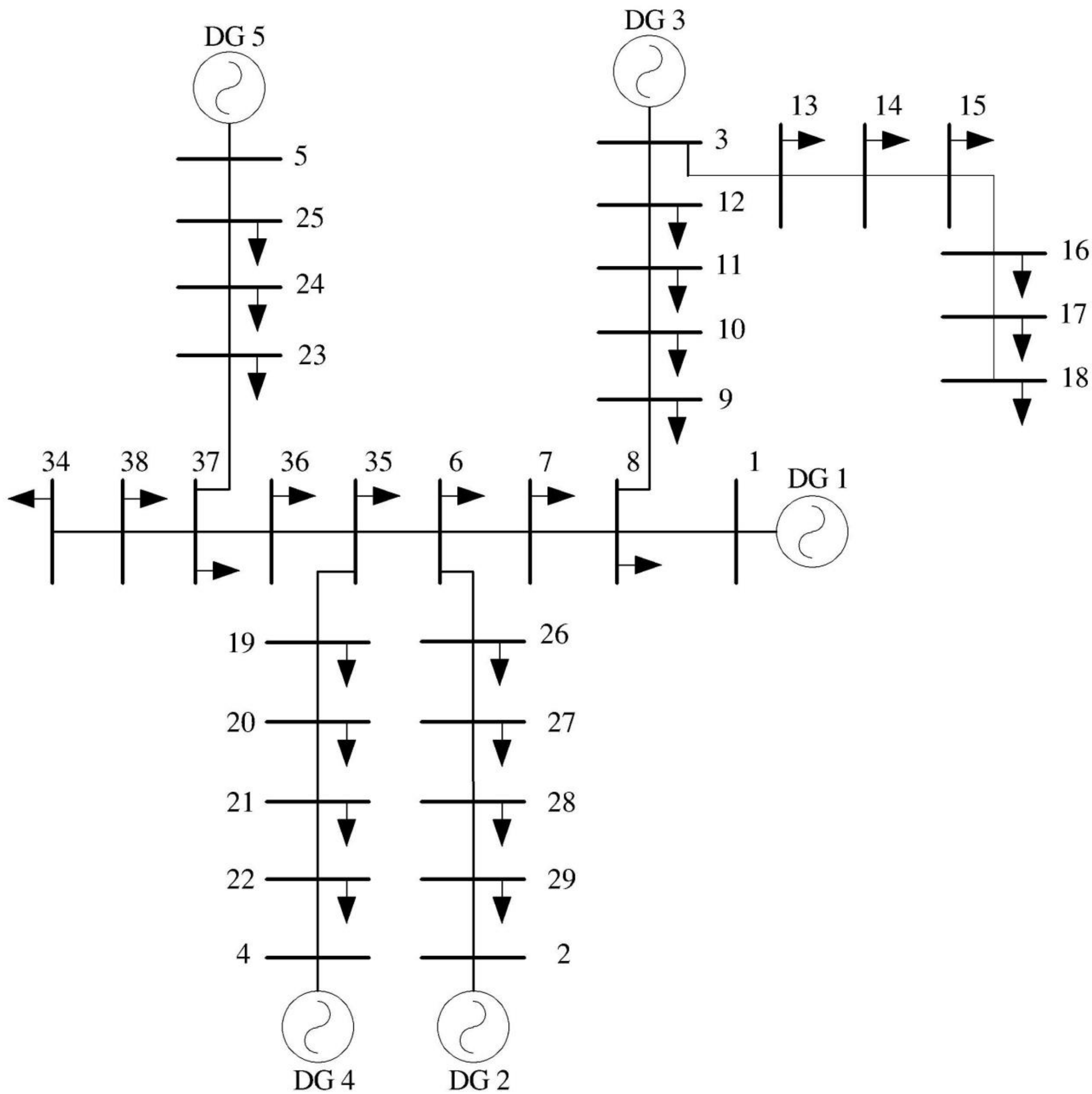

Figure 6 - 38_bus balanced test system

3.2. THREE PHASE UNBALANCED TEST SYSTEM

In this section, the test system is the 25_bus unbalanced system in [21] (Figure 7), the line-data and bus-data are shown in Table VII and Table VIII respectively in *I.2. Chapter 2 of appendix*, and we assume that all of Generators are droop-buses. Many sets of parameters have been tried and a variation in power losses as well as in frequency has been observed. The following underlying hypotheses have been made: the base power and base voltage for per unit calculations have been set to S_B = 30MVA, $V_{\mathbf{B}}$ = 4.16 kV.

Using the proposed method we get the power load flow results (voltage profile and loads in each phase; the real and reactive power in each phase and the total injected power from all the DG units in p.u) are shown in table IV and V respectively.

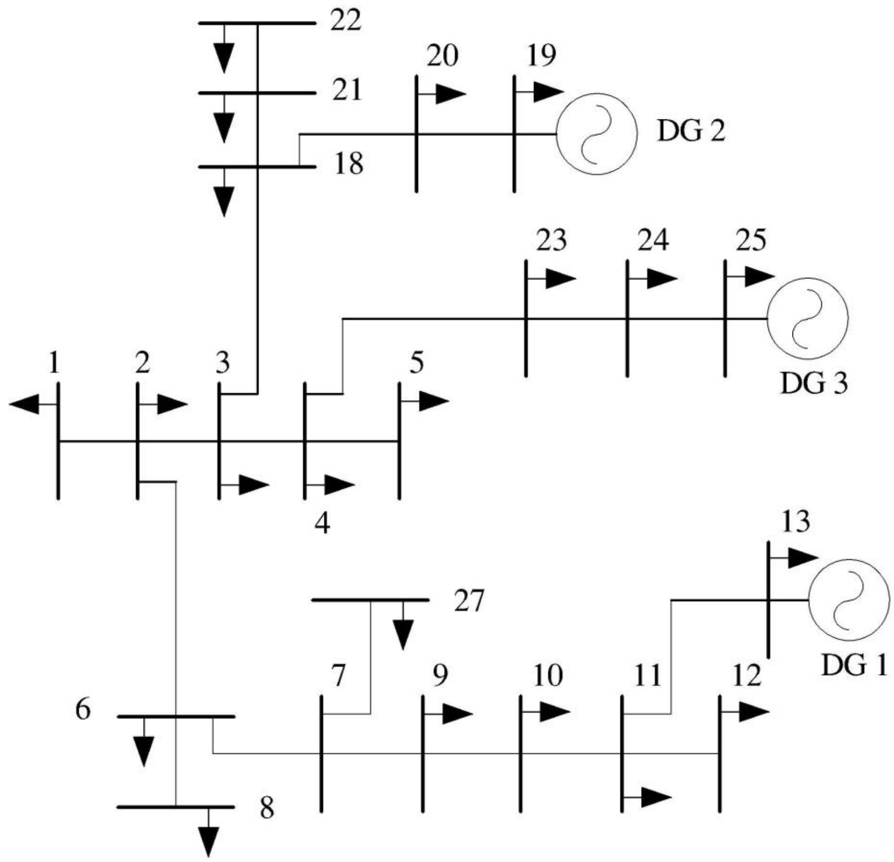

Figure 7 - 25_bus unbalanced test system

TABLE V. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25_BUS UNBALANCED TEST SYSTEM, BASIS CASE

Bus no	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9775	0.0000	0.0000	0.0000	0.9750	-2.0877	0.0000	0.0000	0.9749	2.0931	0.0000	0.0000
2	0.9775	0.0000	0.0000	0.0000	0.9750	-2.0877	0.0000	0.0000	0.9749	2.0931	0.0000	0.0000
3	0.9780	0.0004	0.0012	0.0007	0.9755	-2.0876	0.0013	0.0009	0.9753	2.0933	0.0015	0.0009
4	0.9782	0.0009	0.0016	0.0012	0.9757	-2.0872	0.0019	0.0014	0.9755	2.0936	0.0022	0.0011
5	0.9745	-0.0007	0.0013	0.0009	0.9717	-2.0885	0.0012	0.0008	0.9709	2.0913	0.0016	0.0009
6	0.9659	-0.0030	0.0013	0.0005	0.9639	-2.0879	0.0015	0.0009	0.9649	2.0928	0.0012	0.0007
7	0.9654	-0.0027	0.0000	0.0000	0.9643	-2.0869	0.0000	0.0000	0.9645	2.0939	0.0000	0.0000
8	0.9578	-0.0058	0.0011	0.0003	0.9561	-2.0888	0.0014	0.0009	0.9578	2.0919	0.0012	0.0008
9	0.9776	0.0026	0.0020	0.0013	0.9773	-2.0840	0.0017	0.0012	0.9776	2.0982	0.0017	0.0010
10	0.9952	0.0079	0.0012	0.0008	0.9947	-2.0813	0.0013	0.0010	0.9946	2.1028	0.0015	0.0010
11	1.0157	0.0131	0.0015	0.0009	1.0156	-2.0790	0.0012	0.0007	1.0151	2.1075	0.0014	0.0009
12	1.0200	0.0184	0.0017	0.0013	1.0193	-2.0746	0.0020	0.0016	1.0183	2.1121	0.0024	0.0014
13	**1.0357**	**0.0133**	**0.0012**	**0.0009**	**1.0357**	**-2.0811**	**0.0016**	**0.0012**	**1.0357**	**2.1077**	**0.0014**	**0.0011**
14	0.9557	-0.0063	0.0016	0.0006	0.9545	-2.0886	0.0019	0.0007	0.9547	2.0916	0.0022	0.0010
15	0.9519	-0.0078	0.0041	0.0014	0.9521	-2.0898	0.0031	0.0010	0.9537	2.0915	0.0023	0.0011

16	0.9623	-0.0040	0.0015	0.0004	0.9615	-2.0871	0.0012	0.0005	0.9608	2.0928	0.0017	0.0007
17	0.9533	-0.0075	0.0012	0.0003	0.9515	-2.0883	0.0011	0.0007	0.9509	2.0909	0.0015	0.0009
18	0.9859	-0.0046	0.0012	0.0008	0.9836	-2.0938	0.0013	0.0009	0.9825	2.0888	0.0015	0.0010
19	**1.0468**	**-0.0213**	**0.0021**	**0.0018**	**1.0468**	**-2.1157**	**0.0017**	**0.0014**	**1.0468**	**2.0730**	**0.0017**	**0.0016**
20	1.0047	-0.0102	0.0013	0.0010	1.0033	-2.1019	0.0012	0.0008	1.0012	2.0845	0.0015	0.0011
21	0.9779	-0.0036	0.0017	0.0010	0.9755	-2.0918	0.0013	0.0009	0.9745	2.0891	0.0015	0.0010
22	0.9741	-0.0022	0.0016	0.0011	0.9709	-2.0901	0.0019	0.0013	0.9702	2.0896	0.0023	0.0012
23	0.9931	0.0101	0.0020	0.0015	0.9916	-2.0797	0.0016	0.0013	0.9911	2.1024	0.0023	0.0011
24	1.0133	0.0189	0.0012	0.0009	1.0122	-2.0731	0.0014	0.0010	1.0118	2.1121	0.0017	0.0011
25	**1.0365**	**0.0273**	**0.0021**	**0.0017**	**1.0365**	**-2.0671**	**0.0018**	**0.0011**	**1.0365**	**2.1217**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin**	**Vmax**
	0.0357	0.0213	0.0346	0.0223	0.0377	0.0377	0.1080	0.0813	0.9992	0.0060	0.9519	1.0468

Where: Van, Vbn, Vcn are voltage of phase A, phase B, phase C respectively at each bus; Mag, Ang, P, Q are magnitude of voltage, angle voltage, real power load, reactive power load of buses at each phase respectively; Pla, PLb, PLc, QLa, QLb, QLc are total real power load and reactive power load of phase A, phase B, phase C respectively; PLtotal and Qltotal are total real and reactive power load of system; f, Vmin, Vmax are frequency, minimum and maximum voltage in system respectively.

TABLE VI. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25_BUS UNBALANCED TEST SYSTEM

Bus ID of Gen	$\mathbf{P_{Ga}}$	$\mathbf{P_{Gb}}$	$\mathbf{P_{Gc}}$	$\mathbf{Q_{Ga}}$	$\mathbf{Q_{Gb}}$	$\mathbf{Q_{Gc}}$	$\mathbf{P_G}$ **total**	$\mathbf{Q_G}$ **total**
13	0.0092	0.0094	0.0099	0.0066	0.0072	0.0078	0.0285	0.0217
19	0.0096	0.0091	0.0098	0.0104	0.0107	0.0108	0.0285	0.0320
25	0.0188	0.0182	0.0200	0.0056	0.0057	0.0060	0.0570	0.0173

Where: P_{Ga}, P_{Gb}, P_{Gc}, Q_{Ga}, Q_{Gb}, Q_{Gc} are real and reactive generated power at each phase of each generator respectively; $P_G$total and $Q_G$total are total real and reactive generated power of each generator.

Taking the values reported in Table VI for parameters K_{Gi}, K_{di}, V_{0i}, f_{0i} for the inverter interfaced generators, the following results for frequency and power losses are obtained. In all the results reported voltage drops in all buses are below the admissible values (5%).

TABLE VII. GENERAL RESULT

Bus ID of Gen	$\mathbf{K_{di}}$	$\mathbf{V_{0i}}$ **/pu**	$\mathbf{K_{Gi}}$	$\mathbf{f_{0i}}$**/pu**	**f /pu**	**Ploss /pu**	**Vmin /pu**	**Vmax /pu**
13	5.00	1.0400	10.00	1.0020	**0.9992**	**0.0060**	**0.9519**	**1.0468**
19	10.00	1.0500	10.00	1.0020				
25	5.00	1.0400	20.00	1.0020				

Change the value of K_G, K_d, V_0 and f_0 of generators and calculating the power flows, we get the first results that are shown in Tables VII to XI. In all the trials, the parameters that stay unchanged (K_{Gi}, K_{di}, V_{0i}, f_{0i}) assume the values in Table IV. In table VI, only parameter KG_{13} has been changed.

TABLE VIII. LOSSES AND FREQUENCY IN THE TEST SYSTEM, CHANGING KG13

K_{G13}	f/pu	Ploss/pu	Vmin/pu	Vmax/pu
30.00	**1.0000**	**0.0101**	**0.9502**	**1.0454**
20.00	0.9997	0.0075	0.9513	1.0460
10.00	*0.9992*	*0.0060*	*0.9519*	*1.0468*

TABLE IX. LOSSES AND FREQUENCY IN THE TEST SYSTEM, CHANGING K_{G25}

K_{G25}	f/pu	Ploss/pu	Vmin/pu	Vmax/pu
40.00	**1.0000**	**0.0090**	**0.9518**	**1.0455**
30.00	0.9997	0.0074	0.9520	1.0460
20.00	*0.9992*	*0.0060*	*0.9519*	*1.0468*

TABLE X. LOSSES AND FREQUENCY IN THE TEST SYSTEM, CHANGING K_{G13} AND K_{G19}

K_{G13}	K_{G19}	f/pu	Ploss/pu	Vmin/pu	Vmax/pu
10.00	*10.00*	*0.9992*	*0.0060*	*0.9519*	*1.0468*
15.00	15.00	0.9997	0.0055	0.9516	1.0475
15.00	20.00	0.9999	0.0058	0.9509	1.0484
17.00	**20.00**	**1.0000**	**0.0057**	**0.9510**	**1.0482**

TABLE XI. LOSSES AND FREQUENCY IN THE TEST SYSTEM, CHANGING K_{G13} AND F_{025}

K_{G13}	f_{025}	f/pu	Ploss/pu	Vmin/pu	Vmax/pu
10.00	*1.0020*	*0.9992*	*0.0060*	*0.9519*	*1.0468*
10.00	1.0030	0.9996	0.0072	0.952	1.0462
18.00	**1.0030**	**1.0000**	**0.0079**	**0.9516**	**1.0455**
10.00	1.0035	0.9998	0.0080	0.9519	1.0458
13.00	**1.0035**	**1.0000**	**0.0082**	**0.9518**	**1.0456**

TABLE XII. LOSSES AND FREQUENCY IN THE TEST SYSTEM, CHANGING K_{G19} AND F_{025}

K_{G19}	f_{025}	f/pu	Ploss/pu	Vmin/pu	Vmax/pu
10.00	*1.0020*	*0.9992*	*0.0060*	*0.9519*	*1.0468*
15.00	1.0030	0.9999	0.0061	0.9518	1.0472
17.00	**1.0030**	**1.0000**	**0.0060**	**0.9517**	**1.0476**
15.00	1.0031	0.9999	0.0062	0.9519	1.0471
15.00	**1.0032**	**1.0000**	**0.0063**	**0.9519**	**1.0471**

In the tables, in italic, the parameters of *basic case* taking value from table VI, while in bold are evidenced the sets of parameters showing the rated frequency value. As it can be observed, there are many different sets of parameters (marked in bold in each table) satisfying the condition f = 50Hz, in all cases, however, the frequency does not vary for more than 0.2 Hz as prescribed by the IEEE standard while power losses change. So it means that changing system parameters will produce a change of the power loss in the system. **With f within the admissible range, the set of parameters satisfying the condition of minimum power losses can thus be chosen for optimal system operation.**

4. CONCLUSIONS

This chapter proposes the use of the Trust Region Method to solve the power flow problem in 3 phase balanced and unbalanced microgrid system. Authors have applied the proposed method on many kind of test system in both balanced and unbalanced mode. In the 25_test bus unbalanced system, the results shows how the power losses term varies as the regulators parameters vary as well, thus showing that these are sensitive parameters that could have an important role in optimal management of such systems. These results suggest an idea for further work on optimal system operation considering also stability issues.

CHAPTER 3: OPTIMAL POWER FLOW IN THREE-PHASE ISLANDED MICROGRIDS WITH INVERTER INTERFACED UNIT BASED ON LAGRANGE METHOD

1. INTRODUCTION

In this chapter, the solution of the OPF problem for three phase islanded microgrids is studied, the OPF being one of the core functions of the tertiary regulation level for an AC islanded microgrid with a hierarchical control architecture. The study also aims at evaluating the contextual adjustment of the droop parameters used for primary voltage and frequency regulation of inverter interfaced units. The work proposes a mathematical method for the OPF solution also considering the droop parameters as variables. The output of the OPF provides an iso-frequential operating point for all the generation units and a set of droop parameters for primary regulation. In this way, secondary regulation can be neglected in the considered hierarchical control structure. Finally, the application section provides the solution of the OPF problem over networks of different sizes and a stability analysis of the microgrid system using the optimized droop parameters, thus giving rise to the optimized management of the system with a new hierarchical control architecture.

2. OPTIMAL POWER FLOW CALCULATION

The OPF in this paper is carried out to minimize power losses. The solution algorithm is iterative and uses Lagrange method. The solution strategy has proved to be efficient for the definition of new operating points and new droop parameters for primary regulation; moreover, the proposed architecture integrating the proposed OPF may replace the secondary regulation level by finding an iso-frequency working condition for all units. It has indeed been shown, through parametric studies, in Chapter 2, that the power losses term is of course connected to the droop parameters values and thus such choice influences the steady state operation of microgrids.

Moreover sharing power among units so as to get a minimum loss operation will lead also to increased stability margins and probably a stable operation as proved in [22], [23].

The role of the OPF in the proposed controller architecture is depicted in figure 8 below and expressed by the following formula.

$$f = (f_{0i} + \Delta f) - (K_{Gi} + \Delta K_{Gi}) * (P_{Gri} - P_{0Gri}) \qquad (28)$$

where:

f_{0i} and P_{0Gri} are the rated frequency and power of generator i

f and P_{Gri} are frequency and generated power of generator i at the new operating point

Δf and ΔK_{Gi} are frequency deviation and droop parameter to get the new operating point, respectively carried out by secondary and tertiary control. In this way, the OPF outputs a new operating point at a new frequency and also resets the different primary regulation parameters.

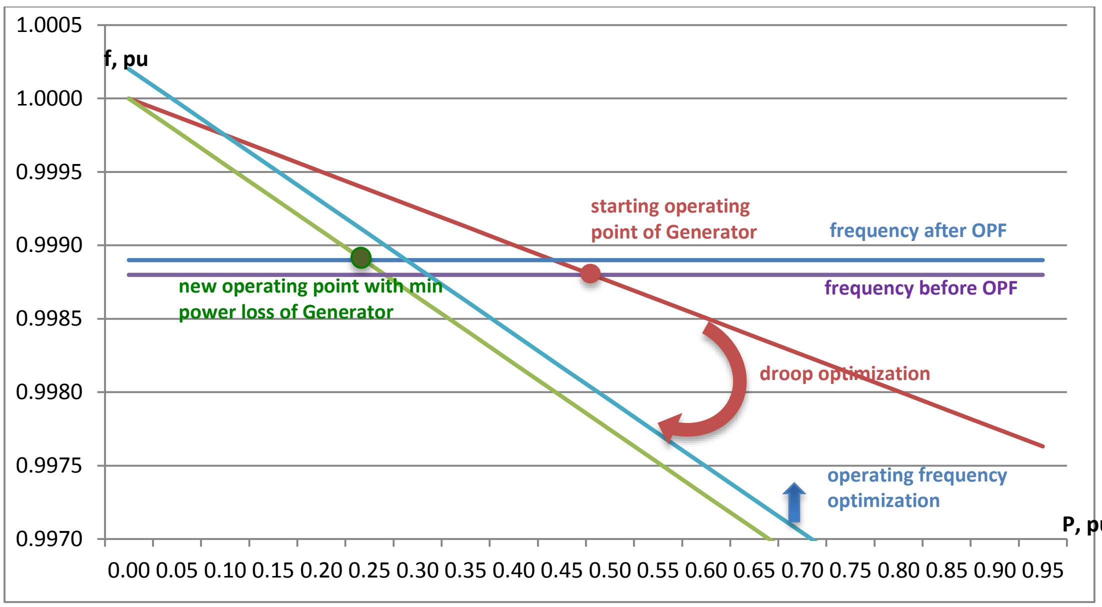

Figure 8 - Action of the OPF in the proposed controller architecture

A general formulation for the power losses equation, referred to as *Kron's loss formula*, is the following [24]:

$$P_{Loss} = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_{Gi} B_{ij} P_{Gj} + \sum_{i=1}^{n_g} B_{0i} P_{Gi} + B_{00} \quad (29)$$

Where:

n_g is the number of generators (including of droop generators (n_{gr}) and PQ generators (n_{PQ})),

P_{Gi} and P_{Gj} are matrix of generated real powers

$$P_{Gj} = \begin{bmatrix} P_{G1} \\ P_{G2} \\ \vdots \\ P_{Gng} \end{bmatrix}; \quad P_{Gi} = [P_{G1} \quad P_{G2} \quad \dots \quad P_{Gng}] \quad (30)$$

B_{ij}, B_{0i} and $B_{00}$are loss coefficients or B-coefficients.

Such formulation linearly relates the power losses with the generated powers, considering constant the system's frequency and bus voltages modules and displacements. Although the expression was originally written for transmission systems, it can also be used for microgrids, since it does not imply any assumption that is strictly valid for transmission. Besides, in the solution algorithm, the B-coefficients formulation for power losses is re-calculated at each iteration and this will be cleared out in later. The algorithm repeatedly calculates the system's electrical parameters (voltages modules, voltages displacements and frequency) through the solution of the power flow for new values of the generated power. Nonetheless, since the B-coefficient formulation is adequate for systems that have balanced loads, this hypothesis is a basic assumption to use the proposed method.

The three phase injected real and reactive power from a DG unit which is Droop_bus are calculated in (4) and (5) and in this application, the reactive power depends on voltage but the relevant parameter (K_{di}) can not be optimized.

The optimal dispatch problem is thus that to find the set of droop parameters (K_{Gi}) and generating powers (P_{Gi}) minimizing the power losses function expressed in (27), subject to the constraint that generation should equal total demands plus losses

$$\sum_{i=1}^{n_{gr}} P_{Gri} + \sum_{i=1}^{n_{PQ}} P_{PQi} = \sum_{i=1}^{n_d} P_{Li} + P_{Loss} \quad (31)$$

where P_{Gri} is the real power of droop_generator i; P_{PQi} is the real power of PQ_generator i; P_{Li} is the real power of load bus i and n_d is the number of load bus.

The problem should also meet the following inequality constraints, expressed as follows:

$$K_{Gimin} \leq K_{Gi} \leq K_{Gimax}, i = 1 \text{ to } n_{gr} \qquad (32)$$

$$P_{PQimin} \leq P_{PQi} \leq P_{PQimax}, i = 1 \text{ to } n_{PQ} \qquad (33)$$

where the K_{Gi} is a coefficient characterizing the droop regulator of droop_bus generator i, I_{mni} is the current on branch *mn* connecting buses m and n.

Following the Lagrange method, we obtain

$$L = P_{Loss} + \lambda\left(\sum_{i=1}^{n_d} P_{Li} + P_{Loss} - \sum_{i=1}^{n_{gr}} P_{Gri} - \sum_{i=1}^{n_{PQ}} P_{PQi}\right) + \sum_{i=1}^{n_{gr}} \mu_{i(max)}\left(K_{Gi} - K_{Gi(max)}\right) + \sum_{i=1}^{n_{gr}} \mu_{i(min)}\left(K_{Gi} - K_{Gi(min)}\right) + \sum_{i=1}^{n_{PQ}} \gamma_{i(max)}\left(P_{PQi} - P_{PQimax}\right) + \sum_{i=1}^{n_{PQ}} \gamma_{i(min)}\left(P_{PQi} - P_{PQimin}\right) \quad (34)$$

where λ, $\mu_{i(max)}$, $\mu_{i(min)}$, $\gamma_{i(max)}$, $\gamma_{i(min)}$ are the Lagrange multiplier and the $\mu_{i(max)} = 0, \gamma_{i(max)} = 0$ when $K_{Gi} < K_{Gimax}$, $P_{PQi} < P_{PQimax}$; $\mu_{i(min)} = 0$, $\gamma_{i(min)} = 0$ when $K_{Gi} > K_{Gimin}$, $P_{PQi} > P_{PQimin}$. It means that if the constraint is violated, it will become active. To get the solution of the problem, we have to solve the set of equations include of the partials of the function below:

$$\frac{\partial L}{\partial K_{Gi}} = 0 \qquad (35)$$

$$\frac{\partial L}{\partial P_{PQi}} = 0 \qquad (36)$$

$$\frac{\partial L}{\partial \lambda} = 0 \qquad (37)$$

$$\frac{\partial L}{\partial \mu_{max}} = K_{Gi} - K_{Gi(max)} = 0 \qquad (38)$$

$$\frac{\partial L}{\partial \mu_{min}} = K_{Gi} - K_{Gi(min)} = 0 \qquad (39)$$

$$\frac{\partial L}{\partial \gamma_{max}} = P_{PQi} - P_{PQi(max)} = 0 \qquad (40)$$

$$\frac{\partial L}{\partial \gamma_{min}} = P_{PQi} - P_{PQi(min)} = 0 \qquad (41)$$

Equations (38), (39), (40) and (41) mean that when K_{Gi} and P_{PQi} are within their limits, we will have:

$$\mu_{i(min)} = \mu_{i(max)} = 0 \quad (42)$$

and

$$\gamma_{i(min)} = \gamma_{i(max)} = 0 \quad (43)$$

First condition, given by (35) results in

$$\frac{\partial L}{\partial K_{Gi}} = \frac{\partial P_{Loss}}{\partial K_{Gi}} + \lambda\left(\frac{\partial \sum_{i=1}^{n_d} P_{Li}}{\partial K_{Gi}} + \frac{\partial P_{Loss}}{\partial K_{Gi}} - \frac{\partial \sum_{i=1}^{n_{gr}} P_{Gri}}{\partial K_{Gi}} - \frac{\partial \sum_{i=1}^{n_{PQ}} P_{PQi}}{\partial K_{Gi}}\right) = 0 \quad (44)$$

Since

$$\frac{\partial \sum_{i=1}^{n_{gr}} P_{Gri}}{\partial K_{Gi}} = \frac{dP_{Gri}}{dK_{Gi}} = -(f - f_{0i}) \quad (45)$$

$$\frac{\partial \sum_{i=1}^{n_{PQ}} P_{PQi}}{\partial K_{Gi}} = 0 \quad (46)$$

$$\frac{\partial \sum_{i=1}^{n_d} P_{Li}}{\partial K_{Gi}} = \frac{dP_{Li}}{dK_{Gi}} = 0 \quad (47)$$

And therefore the condition for optimum dispatch becomes

$$\frac{\partial P_{Loss}}{\partial K_{Gi}}(\lambda + 1) + \lambda(f - f_{0i}) = 0 \quad (48)$$

Since

$$\frac{\partial P_{Loss}}{\partial K_{Gi}} = (f - f_{0i})\left(-2\sum_{j=1}^{n_g} B_{ij}P_{Gj} - B_{0i}\right) \quad (49)$$

substituting in (48) we have

$$\left\{2\sum_{j=1}^{n_g} B_{ij}P_{Gj} + B_{0i}\right\}(\lambda + 1) - \lambda = 0 \quad (50)$$

or

$$B_{ii}(f - f_{oi})K_{Gi} - \sum_{\substack{j=1 \\ j \neq i}}^{ng} B_{ij}P_{Gj} = \frac{B_{0i}}{2} - \frac{\lambda}{2(\lambda+1)} \quad (51)$$

Second condition, given by (36) results in

$$\frac{\partial L}{\partial P_{PQi}} = \frac{\partial P_{Loss}}{\partial P_{PQi}} + \lambda \left(\frac{\partial \sum_{i=1}^{n_d} P_{Li}}{\partial P_{PQi}} + \frac{\partial P_{Loss}}{\partial P_{PQi}} - \frac{\partial \sum_{i=1}^{n_{gr}} P_{Gri}}{\partial P_{PQi}} - \frac{\partial \sum_{i=1}^{n_{PQ}} P_{PQi}}{\partial P_{PQi}} \right) = 0 \quad (52)$$

Since

$$\frac{\partial \sum_{i=1}^{n_{gr}} P_{Gri}}{\partial P_{PQi}} = 0 \quad (53)$$

$$\frac{\partial \sum_{i=1}^{n_{PQ}} P_{PQi}}{\partial P_{PQi}} = 1 \quad (54)$$

$$\frac{\partial \sum_{i=1}^{n_d} P_{Li}}{\partial P_{PQi}} = \frac{dP_{Li}}{dP_{PQi}} = 0 \quad (55)$$

And therefore the condition for optimum dispatch becomes

$$\frac{\partial P_{Loss}}{\partial P_{PQi}}(\lambda + 1) - \lambda = 0 \qquad (56)$$

Since

$$\frac{\partial P_{Loss}}{\partial P_{PQi}} = 2\sum_{j=1}^{n_g} B_{ij}P_{Gj} + B_{0i} \quad (57)$$

substituting in (56) we have

$$\left\{2\sum_{j=1}^{n_g} B_{ij}P_{Gj} + B_{0i}\right\}(\lambda + 1) - \lambda = 0 \qquad (58)$$

or

$$B_{ii}P_{PQi} + \sum_{\substack{j=1 \\ j \neq i}}^{ng} B_{ij}P_{Gj} = \frac{\lambda}{2(\lambda+1)} - \frac{B_{0i}}{2} \qquad (59)$$

Third condition, given by (37) results in

$$\sum_{i=1}^{n_d} P_{Li} + P_{Loss} - \sum_{i=1}^{n_{gr}} P_{Gri} - \sum_{i=1}^{n_{PQ}} P_{PQi} = 0 \qquad (60)$$

Expressing (51) and (59) in form of matrix, we have

$$\begin{bmatrix} B_{11} & B_{12} & \cdots & B_{1ng} \\ B_{21} & B_{22} & \cdots & B_{2ng} \\ \vdots & \vdots & \ddots & \vdots \\ B_{ng1} & B_{ng2} & \cdots & B_{ngng} \end{bmatrix} \begin{bmatrix} K_{G1}(f-f_{01}) \\ K_{G2}(f-f_{02}) \\ \vdots \\ -P_{PQ1} \\ \vdots \\ K_{Gng}(f-f_{0ng}) \end{bmatrix} = \frac{1}{2} \begin{bmatrix} B_{01} - \frac{\lambda}{\lambda+1} \\ B_{02} - \frac{\lambda}{\lambda+1} \\ \vdots \\ B_{0ng} - \frac{\lambda}{\lambda+1} \end{bmatrix} \quad (61)$$

We use the gradient method to solve this set of equation in (61). First, we estimated an initial value of $\lambda^{(k)}$, then we can solve the set of linear equations. From (61), formulation to calculate K_{Gi} at the k_{th} iteration can be extracted as

$$K_{Gi}{}^{(k)} = \frac{B_{oi}(\lambda^{(k)}+1) - \lambda^{(k)} - 2(\lambda^{(k)}+1)\sum_{\substack{j=1 \\ j\neq i}}^{ng} B_{ij} K_{Gj}{}^{(k)}(f-f_{0j})}{2(\lambda^{(k)}+1)B_{ii}(f-f_{0i})} \quad (62)$$

From (61), formulation to calculate P_{PQi} at the k_{th} iteration can be extracted as

$$P_{PQi}{}^{(k)} = \frac{-B_{oi}(\lambda^{(k)}+1) + \lambda^{(k)} - 2(\lambda^{(k)}+1)\sum_{\substack{j=1 \\ j\neq i}}^{ng} B_{ij} P_{Gj}{}^{(k)}}{2(\lambda^{(k)}+1)B_{ii}} \quad (63)$$

Substituting for K_{Gi} from (62) in (5) to get P_{Gri} and then substituting P_{PQi} from (63) and P_{Gri} in (60) we have

$$-\sum_{i=1}^{ngr} \frac{B_{oi}(\lambda^{(k)}+1) - \lambda^{(k)} - 2(\lambda^{(k)}+1)\sum_{\substack{j=1 \\ j\neq i}}^{ng} B_{ij} K_{Gj}{}^{(k)}(f-f_{0j})}{2(\lambda^{(k)}+1)B_{ii}} + \sum_{i=1}^{nPQ} \frac{-B_{oi}(\lambda^{(k)}+1) + \lambda^{(k)} - 2(\lambda^{(k)}+1)\sum_{\substack{j=1 \\ j\neq i}}^{ng} B_{ij} P_{Gj}{}^{(k)}}{2(\lambda^{(k)}+1)B_{ii}} = \sum_{i=1}^{n_d} P_{Li} + P_{Loss}{}^{(\mathrm{k})} \quad (64)$$

or

$$\sum_{i=1}^{ng} \frac{-B_{oi}(\lambda^{(k)}+1) + \lambda^{(k)} - 2(\lambda^{(k)}+1)\sum_{\substack{j=1 \\ j\neq i}}^{ng} B_{ij} P_{Gj}{}^{(k)}}{2(\lambda^{(k)}+1)B_{ii}} = \sum_{i=1}^{n_d} P_{Li} + P_{Loss}{}^{(\mathrm{k})} \quad (65)$$

or

$$g(\lambda^{(k)}) = \sum_{i=1}^{n_d} P_{Li} + P_{Loss}{}^{(\mathrm{k})} \quad (66)$$

Expanding $g(\lambda^{(k)})$ in Taylor's series about an operating point $\lambda^{(k)}$, and neglecting the higher-order terms we get

$$g(\lambda^{(k)}) + \left(\frac{dg(\lambda)}{d\lambda}\right)^{(k)} \Delta\lambda^{(k)} = \sum_{i=1}^{n_d} P_{Li} + P_{Loss}{}^{(\mathrm{k})} \qquad (67)$$

or

$$\Delta\lambda^{(k)} = \frac{\sum_{i=1}^{n_d} P_{Li} + P_{Loss}{}^{(\mathrm{k})} - g(\lambda^{(k)})}{\left(\frac{dg(\lambda)}{d\lambda}\right)^{(k)}} = \frac{\Delta P^{(k)}}{\sum\left(\frac{dP_i}{d\lambda}\right)^{(k)}} \qquad (68)$$

where

$$\sum_{i=1}^{ng} \left(\frac{dP_i}{d\lambda}\right)^{(k)} = \sum_{i=1}^{ng} \frac{1}{2(\lambda^{(k)}+1)^2 B_{ii}} \qquad (69)$$

and therefore

$$\lambda^{(k+1)} = \lambda^{(k)} + \Delta\lambda^{(k)} \qquad (70)$$

The flowchart of the algorithm is shown in figure 9. To get the solution, first we give an initial value in range of variables: Kg^0 and $P_{PQ}{}^0$, set the accuracy ε and the first value of deviation of real generated power ΔPg^0 and $\Delta P_{PQ}{}^0$ satisfying $\Delta Pg^0 < \varepsilon$ & $\Delta P_{PQ}{}^0 < \varepsilon$. Next we use proposed method in Chapter 2 to calculate load flow. Then B_coefficients are calculated and a new value of K_g and P_{PQ} are received after solving a set of nonlinear equations. ΔPg and ΔP_{PQ} are calculated and compared with accuracy ε. The calculation will not be stopped until satisfying the conditions.

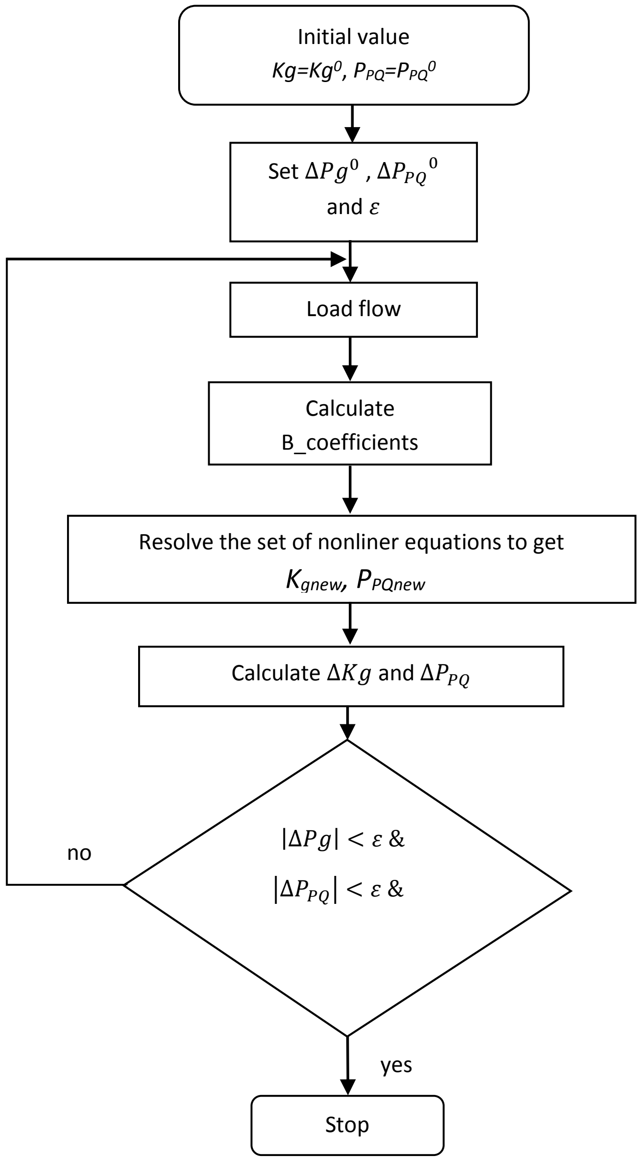

Figure 9 - Flowchart of the algorithm

3. APPLICATIONS

In this section, the OPF algorithm has been applied to 6_bus test system (figure 4), and 38_bus test system (figure 6). For 6_bus test system, stability issue and architecture of the control system are shown and discused.

3.1. APPLICATION ON 38_BUS TEST SYSTEM

The electrical data of 38_bus test system is reported in Tables V and VI in *I. Chapter 2* of the appendix, the limit of KGs are shown in Table XII below. Tables XIII and XIV show the optimal results attained after some iterations of the OPF algorithm applied for the considered 38_bus test system. The general OPF result and more details about load flow result of each iteration are shown in Tables I-III in *II. Chapter 3* of the appendix.

TABLE XIII. LIMIT OF KGS ON 38_ BUS SYSTEM

N0. Generator	Type Generator	Min K_G, pu	Max K_G, pu
1	Droop	100.00	450.00
2	Droop	100.00	450.00
3	Droop	100.00	450.00
4	Droop	100.00	450.00
5	Droop	100.00	450.00

TABLE XIV. RESULT OF OPTIMAL LOAD FLOW ON 38_BUS SYSTEM, PU

Operating point	KG1	KG2	KG3	KG4	KG5	Ploss (*calculated by B coefficients*)
Initial	394.0497	234.0497	214.0497	194.0497	234.0497	0.0546
Optimal	*256.2716*	*281.2228*	*250.8125*	*229.3306*	*251.1261*	*0.0478*

As it can be observed, for the considered loading condition, a reduction of 12.43% of power losses is attained.

3.2. APPLICATION ON 6_BUS TEST SYSTEM

The load data of 6_bus test system is reported in Table XV (base case). Then the dynamic behavior of the system has been tested to check the stability of the attained operating point and relevant droop operation parameters. The electrical data of the test system are similar to [17], they are shown in Tables XVI-XVII below; S_B = 10000kVA, V_B = 230V, f = 60Hz, $K_{pf} = K_{qf} =$

0 (in eqns. (3) and (4)). Table XVIII shows the optimal results attained after some iterations of the OPF algorithm applied for the considered 6_bus test system. The general OPF result and more details about load flow result of each iteration is shown in Tables IV-VII in *II. Chapter 3* of the appendix.

TABLE XV. BUS DATA OF 6_BUS TEST SYSTEM

Bus number	Load, per-phase		Generator				Exponent of Loads	
	R, Ohm	L, mH	Kdi	VG0i, V	KGi	2*pi*f0i, rad/s	Alpha	Beta
1	0.0000	0.0000	17.69231	230.00	401.0638	377.00	0	0
2	0.0000	0.0000	17.69231	230.00	401.0638	377.00	0	0
3	0.0000	0.0000	17.69231	230.00	401.0638	377.00	0	0
4	6.9500	12.2000	0.00	0.00	0.00	377.00	2.00	2.00
5	0.0000	0.0000	0.00	0.00	0.00	377.00	2.00	2.00
6	5.0140	9.4000	0.00	0.00	0.00	377.00	2.00	2.00

TABLE XVI. LINE DATA OF 6_BUS TEST SYSTEM

Bus nl	Bus nr	R, Ohm	L, H
1	4	0.3	0.00035
2	5	0.2	0.00025
3	6	0.05	0.00005
4	5	0.43	0.000318
5	6	0.15	0.001843

TABLE XVII. LIMIT OF KGS ON 6_BUS SYSTEM

N0. Generator	Type Generator	Min K_G, pu	Max K_G, pu
1	Droop	100.00	750.00
2	Droop	100.00	750.00

N0. Generator	Type Generator	Min K_G, pu	Max K_G, pu
3	Droop	100.00	750.00

TABLE XVIII. RESULT OF OPTIMAL LOAD FLOW ON 6_BUS SYSTEM, PU

Operating point	KG1	KG2	KG3	Ploss (*calculated by B coefficients*)
Initial	401.0638	401.0638	401.0638	0.0265391
Optimal	*406.3396*	*221.7403*	*573.4366*	*0.0228142*

As it can be observed, for the considered loading condition, a reduction of 14.04% of power losses is attained. Results of the same OPF procedure carried out for other loading conditions on the same test system that can be experienced realistically (changing the load factor between 0.5 p.u. and 1 p.u.) still show a power losses reduction that does not go below 8% in all cases.

3.2.1. STABILITY ISSUES AND ARCHITECTURE OF THE CONTROL SYSTEM ON 6_BUS TEST SYSTEM

The dynamic behavior of the system with optimized parameters has been tested for a step load change. At t = 10s, a three phase resistor branch (12Ω in each phase) and three phase inductor branch (0.01H in each phase) is added to bus 4 and bus 6 by paralleling respectively.

The simulations, figures 10 and 11 show that the droop parameters found after the OPF application produce stable results. As it was expected, the power sharing condition proposed by the OPF solution increases the output power from the units (DG1 and DG3) that are electrically closer to the loads that have increased their absorption and decreases the contribution from the electrically farthest unit (DG2). Moreover the contextual variation of droop gains in the same direction (increase for those that are closer and decrease for the farthest) implies and even more reactive response if loads will keep varying in the same direction).

Stable behavior was expected since in [23] the stability margins are improved when: loading is shared according to lines capacity and frequency is higher (consequence of lower power losses in islanded systems). What cannot be ensured is of course that power is shared according to DG units capacity.

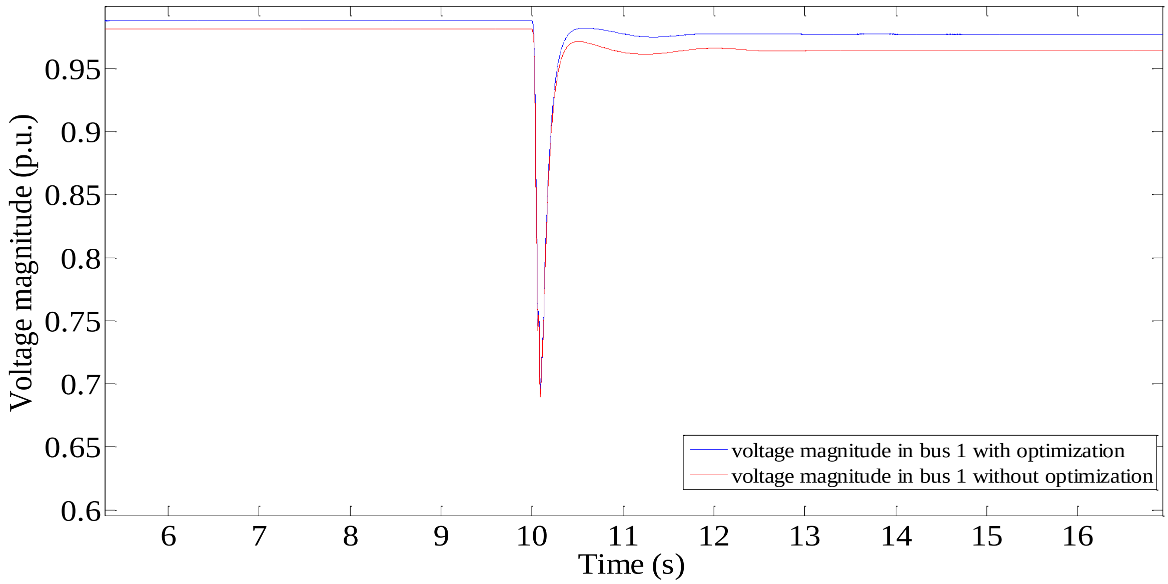

Figure 10 - Comparison of voltage magnitude response in bus1 before and after the optimization

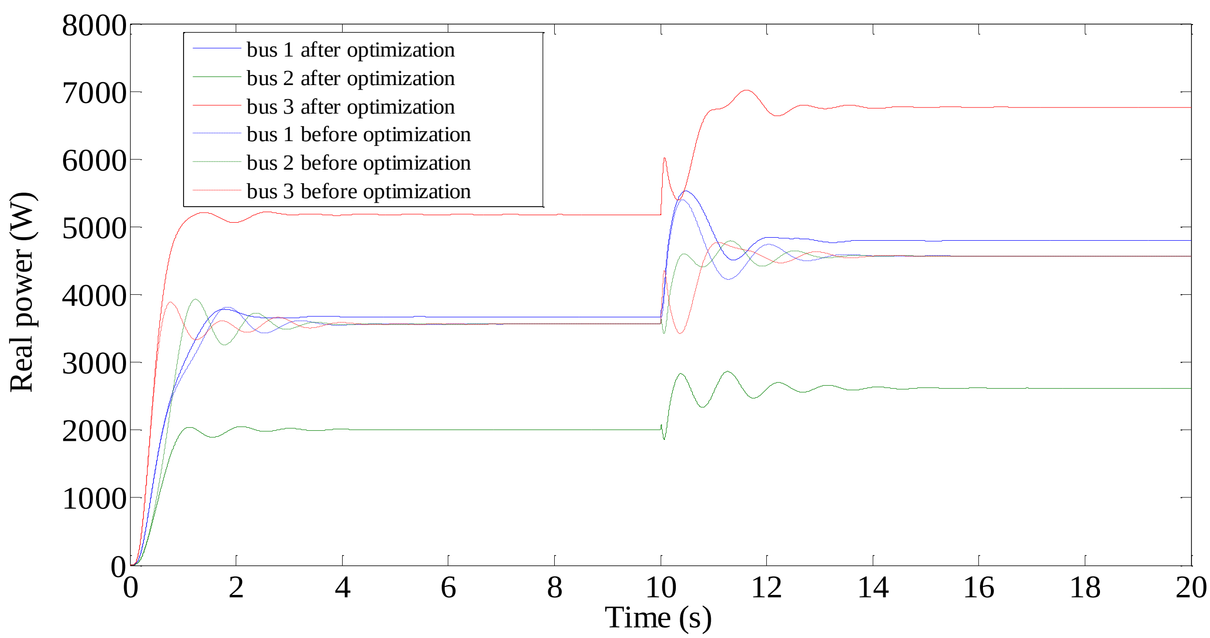

Figure 11 - Comparison of power magnitude response in bus 1, 2, 3 before and after the optimization

The application carried out even if for a simplified case (balanced loads) where only the P-f droop parameters can be optimized shows the possibility to carry out a centralized and optimized control of the system even when the grid is islanded. The load flow method, proposed in the Chapter 2, for unbalanced systems can indeed be easily integrated into a heuristic-based OPF giving rise to solution parameters both for P-f droop generation units and for Q-V droop generation units.

The proposed OPF algorithm to be integrated into a centralized controller of a microgrid would produce reduced losses and voltage drops all over the system. Moreover, if carried out frequently, i.e. every few minutes, it eliminates the need for a distributed secondary regulation, since it produces isofrequential, and within admissible rated bounds, operating points for all droop interfaced generators.

The general architecture of the control system is therefore depicted in figure 12.

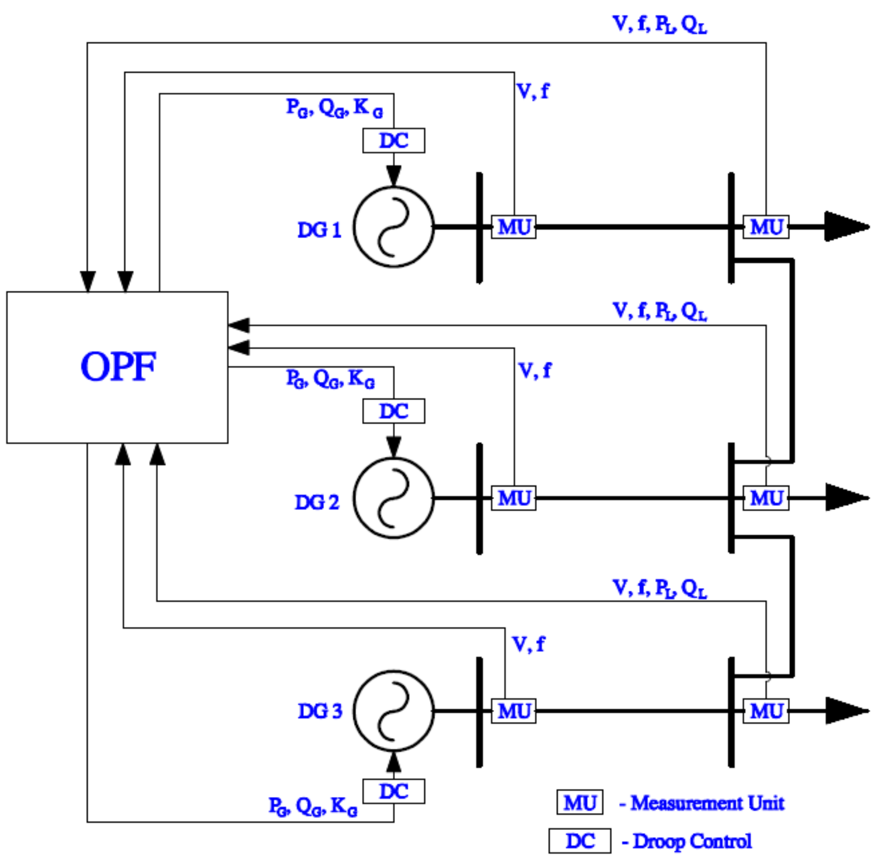

Figure 12 - General architecture of the control system

After a load variation and after the primary regulation, in order to compensate for the frequency and amplitude deviations, the OPF is started. The frequency and voltage amplitude levels in the microgrids f and V at all buses are sensed and compared with the references f^*_{MG} and V^*_{MG}, if the errors are greater than a given threshold (which takes into account the admissible frequency and voltage deviations), then the OPF is started again in order to restore the operating voltage and frequency.

4. CONCLUSIONS

In this Chapter, a new OPF algorithm for islanded microgrids is proposed. The algorithm produces a minimum losses and stable operating point with relevant droop parameters and solves the OPF problem in closed form. It is interesting to point out that the underlying idea of a centralized controller providing operating points at the same frequency and within admissible bounds may lead to a simplified hierarchical structure only including two control levels (primary and tertiary control levels). Nevertheless, at the moment the proposed algorithm cannot deal with unbalanced loads and only outputs results for the P-f droops parameters, letting the Q-V droops parameters non optimized.

The algorithm as it is proposed in this chapter is feasible for small systems where centralized operation is possible and loads are typically balanced.

CHAPTER 4: OPTIMAL POWER FLOW BASED ON GLOW-WORM SWARM OPTIMIZATION FOR THREE-PHASE ISLANDED MICROGRIDS

1. INTRODUCTION

This Chapter presents an application of GSO method, to solve the OPF problem taking into account the constraints of frequency and line ampacity in three-phase islanded Microgrids. Each generation unit is equipped with a Power Electronics Interface. In the considered formulation, the droop control parameters are considered as variables to be adjusted by a higher control level, while the frequency is kept in rated bounds. Another typical constraint for OPF formulation, the max ampacity of each line, is also considered. In this chapter, the authors compare a heuristic method with a numerical method based on the Lagrange method and Trust region method to solve the OPF in islanded migrogrids. As it will be shown, the numerical method does not allow to take into account all the influential features of the OPF problem at hand. On the other hand, a full study taking into account all influential features based on GSO method is also here considered.

Some tests are executed on 6_bus LV systems with balanced loads, the results are compared with those generated by a numerical method based on Lagrange multipliers in case of not taking into account the constraints of frequency and line ampacity. Two case studies taking into account the constraints of frequency and line ampacity with different dimensions and electrical features have been considered and the obtained results show the efficiency of the proposed approach that can be straightforward extended to unbalanced systems.

2. OPTIMAL POWER FLOW CALCULATION

The OPF in this work is solved to minimize power losses and the general model for OPF calculation encompasses power lines, loads, generators, including their control loops such as droop characteristics. The problem is highly non linear. The output variables are new droop parameters for primary regulation, moreover the operating solution produces an iso-frequency working condition for all units with operating frequency within admissible ranges. In [2] it has been shown that the power losses term is connected to the droop parameters values and thus such choice influences the steady state and dynamic operation of the microgrids.

2.1. OPTIMIZATION VARIABLES

In this chapter, both for P-f droop generation units and for Q-V droop generation units, the optimization variables are the parameters of inverter interfaced units K_G and K_d

$$K_G = \left(K_{G1}, K_{G2} \dots, K_{Gn_g}\right) \quad (71)$$

$$K_d = \left(K_{d1}, K_{d2} \dots, K_{dn_g}\right) \quad (72)$$

where n_g is the number of generators. Therefore the generated reactive and real powers P_{Gi} and Q_{Gi} of generator i are respectively expressed as a linear function of voltage and frequency displacements according to the terms (71) and (72). Their expression could be found in Chapter II, equation (6), (7).

2.2. OBJECTIVE FUNCTION (OF)

Let P_i denote the calculated three phase real power injected into the microgrid at bus i. The formulation to calculate P_i can be expressed, as follow:

$$P_{i(Kg,Kd)} = \sum_{j=1}^{n_{br}} |V_i||V_j||Y_{ij}| cos\left(\theta_{ij} - \delta_i + \delta_j\right) \quad (73)$$

where:

V_i and V_j are the voltages at bus i and bus j, depending on Kg and Kd at droop buses.

δ_i and δ_j are the phase angles of the voltages at bus i and bus j, depending on Kg and Kd at droop buses.

Y_{ij} is the admittance of branch ij

θ_{ij} is the phase angle of Y_{ij}

n_{br} is the number of branch connected into bus i

So the total real power loss of the system or OF for three phases balanced system can be calculated as follow:

$$OF_{(Kg,Kd)} = P_{Loss} = \sum_{i=1}^{n_{bus}} \left(P_{i(Kg,Kd)}\right) \quad (74)$$

where n_{bus} is the number of buses in system.

2.3. CONSTRAINTS

The optimal dispatch issue is that to find the set of droop parameters (K_{Gi}) and (K_{di}) and relevant operating frequency and bus voltages minimizing the function expressed in (74), subject to the constraint that generated power should equal total demands plus total power losses (P_{Loss}):

$$\sum_{i=1}^{n_{gr}} P_{Gri} = \sum_{i=1}^{n_d} P_{Li} + P_{Loss} \qquad (75)$$

where P_{Gri} is the real power of generator i; P_{Li} is the real power of load bus i and n_d is the number of load buses.

Under the following inequality constraints, expressed as follows:

$$K_{Gimin} \leq K_{Gi} \leq K_{Gimax}, i = 1 \text{ to } n_g \qquad (76)$$

$$K_{dimin} \leq K_{di} \leq K_{dimax}, i = 1 \text{ to } n_{gr} \qquad (77)$$

$$\Delta f = f - f_0 \leq 0.02 \qquad (78)$$

$$I_{branchi} \leq I_{maxbranchi}, i = 1 \text{ to } n_{br} \qquad (79)$$

where K_{Gimin} , K_{Gimax}, K_{dimin}, K_{dimax} respectively are the minimum and maximum values of the droop parameters for P-f and Q-V droop generators. Δf is the operating frequency deviation, $I_{branchi}$ is the current in the i-th branch and $I_{maxbranchi}$ is the maximum current in the i-th branch and n_{br} is the number of branches in the system.

2.4. HEURISTIC GSO-BASED METHOD

The OF (74) for the considered OPF is highly non linear due to the non linear relation between power losses and generated power. The variables (K_{Gi} and K_{di}) do not appear explicitly in the equation but they are linearly related to the generated power. For this reason, the use of classical non linear optimization methods seems to be inadequate due to the difficulty in including constraints and unbalanced loading conditions.

Moreover, when the OF is highly nonlinear, the search space is typically multimodal. Hence to analyze such complex model it is required to search for a global optimum. The global optimization capability is important when dealing with complex nonlinear models and heuristics can be a suitable choice.

GSO [25] is a relatively recent heuristic method. In GSO, agents are initially randomly deployed in the objective function space. Each agent in the swarm decides the direction of movement by the strength of the signal picked up from its neighbors. This is somewhat similar to the luciferin induced glow of a glowworm which is used to attract mates or prey. The brighter the glow, the more is the attraction. And the best will be chosen as the solution of problem. Therefore, the glowworm metaphor is used to represent the underlying principles of this optimization approach. In this chapter, this methodology solves the issue including constraints about maximum frequency deviation and line ampacity limits to select the solution. Pseudocode of the modified GSO algorithm considering frequency and line ampacity constraints is shown in figure 13 below.

Initialize Archive A
Repeat Until ***Termination Condition***
Do m times
Step 1: deterministic ***choice (selection)*** *of the base vector*
Step 2: probabilistic ***choice (selection)*** *of the target vector (Roulette Wheel technique based on l(t)) considering frequency and line ampacity constraints*
Step 3: ***recombination***
END m
Step 4: create ***new population (replace A)***
END
A= archive
m=archive size

Figure 13 - Pseudocode of the GSO algorithm

When selecting solutions for recombination, those showing frequency and branch currents out of bounds are still kept in the swarm, but are chosen with a lower probability. Fitness is indeed based on ranking of solutions to keep a stable selection pressure in the probabilistic choice of the target vector. Selection probability indeed depends on luciferin, which in turn depends from fitness. For more details refer to [25].

Another issue usually faced when applying GSO is the choice of the Termination Condition. It is difficult to know if the result attained at a given iteration is the best solution. To solve this issue, a number of iterations (*n*) is previously given as Termination Condition. The same parameter *n* can be increased until results with no more improvements or negligible improvements are attained.

3. APPLICATIONS

To assess the accuracy of GSO, it was compared to the Lagrange method, which is a numerical method, as already described in Chapter 3 In order to perform the comparison both constraints on frequency and line ampacity have been neglected and only Kgs have been considered as optimization variables.

3.1. ACCURACY OF RESULTS

In Chapter III a numerical approach based on the Lagrange method is briefly described. It solves the issue of optimal power flow on 3 phase balanced system with generators using inverter interface units for droop regulation of *V* and *f*. The *Kron's loss formula* was used to express the power losses and thus only the *KGs* parameters could be optimized. A comparison about results between Lagrange method and GSO method is done in this section on a 6_bus three phases balanced LV system (figure 4) with ration R/X is around 2.5. The construction, parameters of system and limits of *KG* are shown respectively in Tables I, II, III in *III.1 Chapter 4* of appendix. The results of the Lagrange method and GSO method are respectively shown in Table XIX and Table XX. More details about optimal and load flow results are shown in *III.1 Chapter 4* of appendix.

TABLE XIX. RESULT OF OPTIMAL LOAD FLOW ON 6_BUS SYSTEM BY LAGRANGE METHOD TAKING INTO ACCOUNT KGS, PU

KG1	KG2	KG3	Plossmin	f
19.8331	10.3798	22.1034	0.0178887	1.0525

TABLE XX. RESULT OF OPTIMAL LOAD FLOW ON 6_BUS BALANCED SYSTEM BY GSO HEURISTIC METHOD TAKING INTO ACCOUNT KGS, PU

Random	KG1	KG2	KG3	Plossmin	f
1	20.9933	10.0258	25.0000	0.0178565	1.0536

2	20.4090	9.7189	24.3476	0.0178565	1.0531
3	19.9132	9.5046	23.7349	0.0178565	1.0527
4	19.1041	9.1025	22.7901	0.0178565	1.0520
5	20.8797	9.9530	24.9023	0.0178565	1.0535

From Table XIX and Table XX, we can see that the minimum values of losses found by the algorithms, **Plossmin,** are close, just 0.0000322 deviation between two cases.

The results of the heuristic for this problem could be considered reliable and repeatable. To make sure of this 5 random independent runs of the GSO have been tried and the deviation of results obtained is zero.

On the other hand, the sets of parameters outputted by the two algorithms are different. This means that this OF is multimodal and there are some local maxima at close values.

3.2. OTHER APPLICATIONS WITH VARIABLE KGS AND KDS

In this section, an application of GSO Heuristic method, taking into account both *KGs* and *Kds*, is shown on the same 6_bus test system that is operated in LV with the ration R/X is around 6.4. In this case, it was not possible to compare the results with the numerical method due to the fact that *Kds* could not be optimized as in the Lagrange method.

In this case, due to the high R/X ratio, the virtual impedances at the droop buses was also considered, such as it happens in low voltage systems. Virtual impedances are usually adopted in addition to the conventional droop control of generators in order to improve system stability, reactive power sharing performance and prevent power couplings which are caused by the complex impedance in the parallel system [26-29]. The analysis about impacts of virtual impedance to power flow calculation in LV microgrids is proposed in [30], where it is shown the necessity of an accurate power flow analysis to evaluate the influence of frequency and voltage droop gains, virtual impedance, nominal frequency and nominal voltage on the system power flow by some case studies. The adoption of the virtual impedance in power flow calculations is cleared out in figure 14 below.

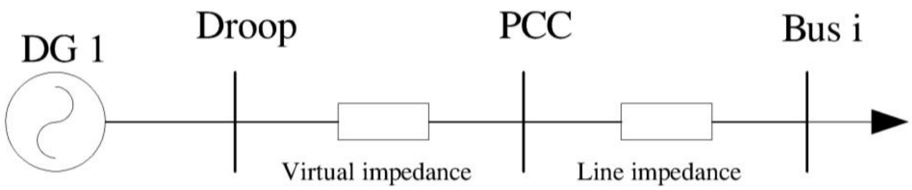

Figure 14 - Virtual impedance control concept

In this way the two regulation channels can be considered as separated simplifying the regulation architecture, and the 6_bus test system is turned on to 9_bus test system as in figure 15 below.

The parameters of 6_bus test system are shown in Tables XVII, XVIII and XIX in *III.2 Chapter 4* of appendix. The optimal results after 5 random cases are shown in Table XXI. More details about optimal result and load flow of each random are shown in *III.2 Chapter 4* of appendix.

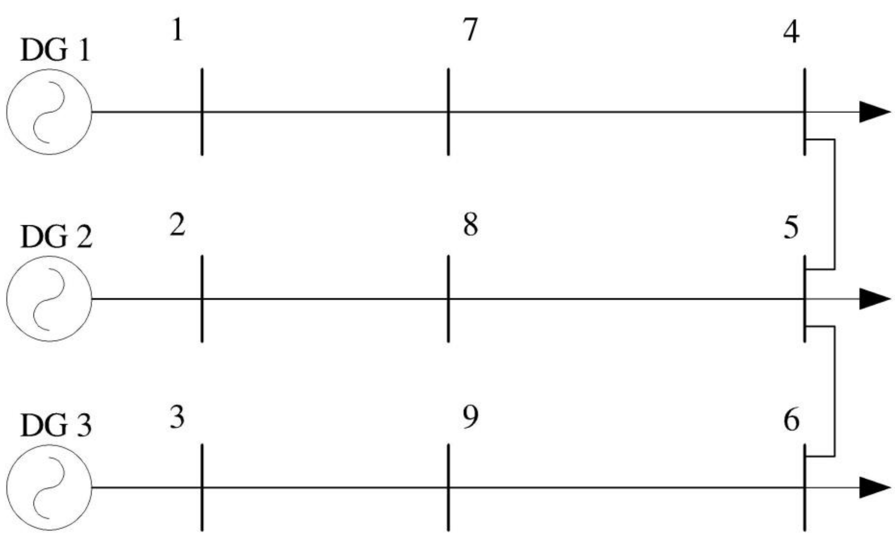

Figure 15 - The 6_bus test system

TABLE XXI. RESULT OF OPTIMAL LOAD FLOW ON 6_BUS TEST SYSTEM TAKING INTO ACCOUNT KGS AND KDS, PU

Random	KG1	KG2	KG3	Kd1	Kd2	Kd3	Plossmin	f
1	9.6625	8.9632	6.9471	6.0000	6.8368	15.6545	0.0001814	0.9949
2	10.2372	9.4079	7.3749	6.0000	6.1705	16.0000	0.0001814	0.9952
3	10.4711	9.6087	7.5745	6.0000	6.2901	16.0000	0.0001814	0.9953
4	10.3483	9.6237	7.3880	6.0113	8.0830	16.0000	0.0001815	0.9953
5	10.5047	9.6305	7.6456	6.0000	6.4065	15.9059	0.0001814	0.9953

From the Table XXI the optimal results of GSO method in 5 randoms are stable, the deviation is only 0.0000001. So in next applications, we could only calculate OPF in 1 random and the results could be believable.

3.3. APPLICATIONS CONSIDERING FREQUENCY AND LINE AMPACITY CONSTRAINTS

3.3.1. APPLICATIONS WITH VARIABLES KGS

In this section, two test cases on a 6_bus balanced test system depicted in figure 4 are presented. To simplify the problem and run a statistically significant sample (50) of test runs, the two runs optimize only the K_{Gi} parameters and are referred to two different sets of line ampacity of branches. The topological and electrical features of the system are shown in Tables XXX and XXXI in *III.3 Chapter 4* of appendix. Limits of KGs, line ampacities of two test cases are shown in Table XXII, XXIII respectively. The load model used in this section depends on voltage and frequency.

The results of the GSO method in the two cases are shown in Table XXIV. More details of optimal result and power flow of two cases are shown in *III.3 Chapter 4* of appendix.

Figure16 shows the OPF operating currents which are also compared with line ampacity on each branch in the two cases.

TABLE XXII. LIMIT OF KGS ON 6_BUS TEST SYSTEM, TAKING INTO ACCOUNT CONSTRAINED FREQUENCY AND LINE AMPACITY WITH VARIABLES ARE KGS, PU

Generators	KGmin,pu	KGmax,pu
G1	1	25
G2	1	25
G3	1	25

Where KGmin and Kgmax are minimum and maximum value of coefficient KG of generators respectively.

TABLE XXIII. LINE AMPACITY OF BRANCHES ON 6_BUS SYSTEM OPTIMIZING KGS, PU

Branch	Imax, pu	
	Case 1	Case 2
L4_5	0.40	0.30
L1_4	0.50	0.47
L2_5	0.50	0.50
L6_5	0.40	0.30
L3_6	0.50	0.60

TABLE XXIV. RESULT OF OPTIMAL LOAD FLOW ON 6_BUS SYSTEM BY GSO HEURISTIC METHOD TAKING INTO ACCOUNT KGS, PU

Case	KG1	KG2	KG3	Plossmin	f
1	8.7549	6.7822	7.2606	0.0352283	0.9808
2	7.6381	7.5541	7.9221	0.0359207	0.9814

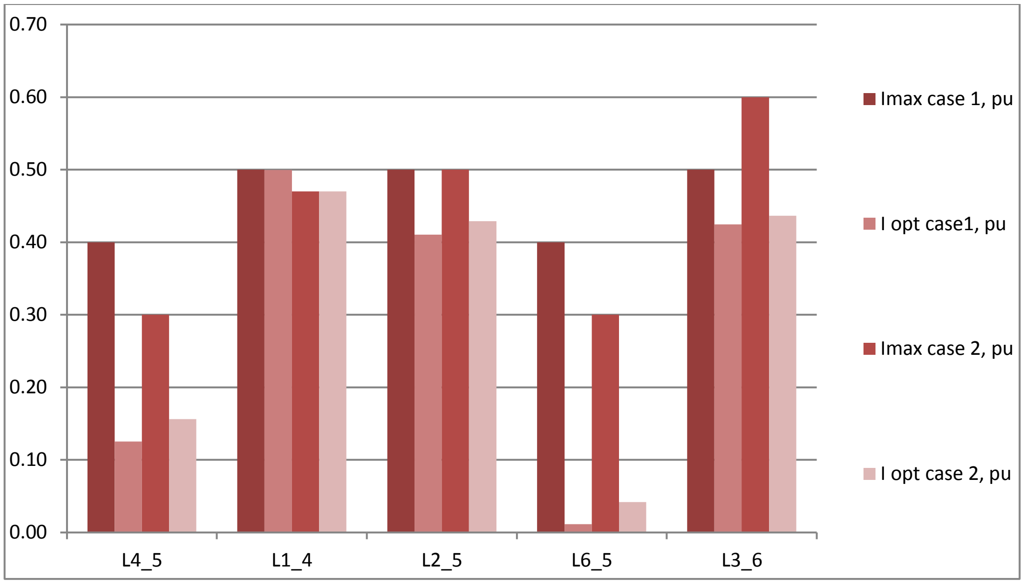

Figure 16 - The OPF operating current in each branch in the two considered cases

In figure 16, *Imax case 1* and *Imax case 2* are the line ampacity on each branch of two test cases; *Iopt case1* and *Iopt case2* are optimal currents on each branch of two test cases; L4_5, L1_4, L2_5, L6_5 and L3_6 are branchs in 6_bus test system. From figure, we could see that at each branch, the optimal currents are lower than the line ampacity in both of two test cases except branch L1_4, the optimal current is equal to line ampacity. And in the table XXIV, the Plossmin in case 2 is bigger than in case 1 as we reduce the line ampacity on branch L1_4. It shows the resonable of the achieved results.

3.3.2. APPLICATION WITH VARIABLES KGS AND KDS

In this section, both sets of K_{Gi} and K_{di}, are optimized. The load model used in this section only depends on voltage ($K_{Gf} = K_{Qf} = 0$). The limits of K_{Gi} and K_{di}, are shown in Table XXV, set of line ampacity of branches is similar to case 1 in Table XXII. The optimal power flow results are shown in Table XXVI. More details of optimal result and optimal power flow are shown in *III.3 Chapter 4* of appendix. In all branches the OPF results produce similar current flows as compared to those in figure16, see figure 17.

TABLE XXV. LIMITS OF KGS AND KDS ON 6_BUS BALANCED TEST SYSTEM OPTIMIZING KGS AND KDS, PU

Generators	KGmin	KGmax	Kdmin	Kdmax
G1	1	25	4	15
G2	1	25	4	15
G3	1	25	4	15

TABLE XXVI. RESULT OF OPTIMAL LOAD FLOW ON 6_BUS SYSTEM, OPTIMIZING KGS AND KDS, PU

KG1	KG2	KG3	Plossmin	f
11.2421	9.4341	9.4641		
Kd1	**Kd2**	**Kd3**	0.0351713	0.9926
4.3345	4.0099	4.3574		

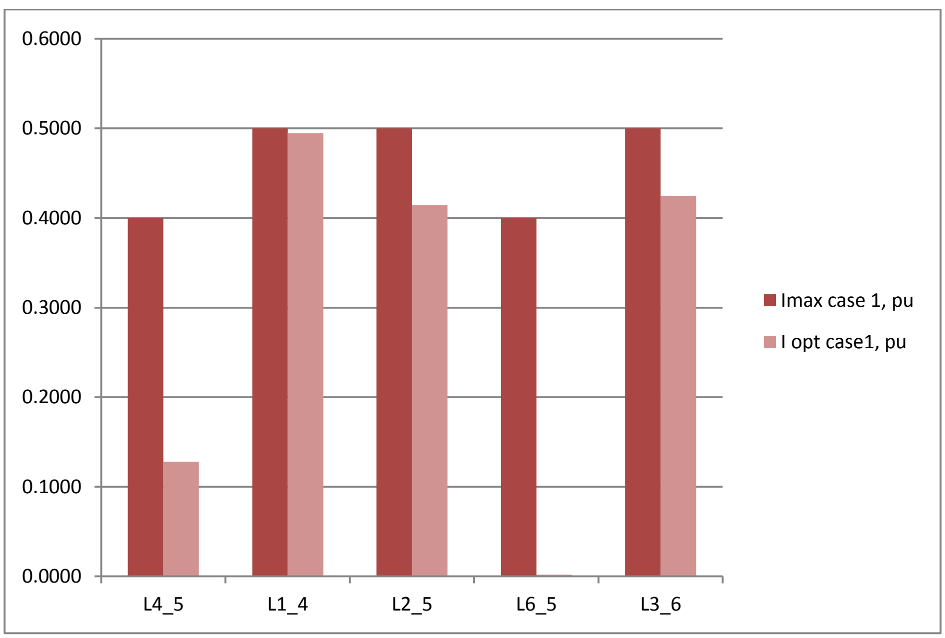

Figure 17 - The OPF operating current in each branch

Besides it can be observed that these flows are lower than the limit. In this application, the set of line ampacity is the same with in *3.3.1-case 1*, however we take into account more variables, both KGs ans Kds, the better operating point has been given with Plossmin in Table XXVI is smaller than in *3.3.1-case 1* even that just small deviation (0.000057). The possibility to optimize also the reactive power dispatch provides indeed more flexibility.

The attained results are reasonable and show that the proposed algorithm is effective, being able to find a solution that satisfies the frequency and line ampacity constraints for a 6_bus test system. All the reported results refer to a set of parameters showing the highest frequency of occurrence within the considered sample of runs.

4. CONCLUSIONS

This chapter introduces an application of GSO method to solve the problem of OPF in islanded three-phase microgrids. The system is supplied by inverter interfaced units with droop controllers. Both P-f droops parameters and Q-V droops parameters are considered as variables and constraints keep the current in branches below rated ampacity and frequency within given bounds. Some tests are executed on 6_bus balanced systems to prove the efficiency of the proposed approach. The flexibility of the considered solution approach allows the consideration of unbalanced loads and further work will also be addressed to reduce calculation times.

CHAPTER V. CONCLUSIONS

This work has been focused on Optimal power flow issue in islanded microgrids in which inverter interfaced units have an important role on operating and control. A load flow method taking into account the model of these units has been used in this work to support the OPF both using a numerical method and using a heuristic method.

The load flow solution uses a matlab solver, the results of applications on many kind of islanded microgrid systems with different R/X ratios and sizes have shown the effectiveness and correctness of the proposed method.

Then two original OPF methods, one based on a numerical approach and another based on a heuristic approach, have been proposed to find out the optimal operating point for an islanded MGs. The dependency in the modeling of all components on voltage and frequency allows to use the OPF as a substitute of secondary regulation, provided it can be perfomed in reasonable calculation times.

The numerical method uses a Lagrange approach. It has been applied on two islanded microgrid test systems, 6_bus and 38_bus test system. The results have shown that this method can give a good result on both low voltage and medium voltage systems and on various kind of microgrid system in a few iterations and in limited running time. The application carried out, for balanced loads and where only the P-f droop parameters can be optimized, shows the possibility to carry out a centralized and optimized control of the system even when the grid is islanded.

The heuristic method is based on the Glow-worm Swarm optimizer. It effectively solves the OPF and can account for constraints such as frequency in certain boundaries and line ampacity. This method gives rise to solution parameters both for P-f droop generation units and for Q-V droop generation units; it has been applied on 6_bus test system in many scenarios. The application results have shown the effectiveness and correctness of it. However, the calculating speed should be improved in the future to make it feasible for real world applications.

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APPENDIX

I. CHAPTER 2

I.1. Three phase balanced system

I.1.1. 6_bus test system

TABLE I. LINE_DATA OF 6_BUS BALANCED SYSTEM, PU

Bus nl	Bus nr	R	X
4	5	0.028355	0.011816
4	1	0.056711	0.024943
5	2	0.037807	0.017816
5	6	0.028355	0.011816
6	3	0.056711	0.024943

TABLE II. BUS_DATA OF 6_BUS SYSTEM, PU

Bus number	Load		Generator				Exponent of Loads	
	P	Q	Kdi	VG0i	KGi	f0	Alpha	Beta
1	0.0000	0.0000	27.6923	1.00	369.5805	1	0.00	0.00
2	0.0000	0.0000	27.6923	1.00	314.7062	1	0.00	0.00
3	0.0000	0.0000	27.6923	1.00	497.9019	1	0.00	0.00
4	0.7888	0.4501	0.0000	1.00	0.0000	1	2.00	2.00
5	0.4345	0.2245	0.0000	1.00	0.0000	1	2.00	2.00
6	0.7536	0.4473	0.0000	1.00	0.0000	1	2.00	2.00

I.1.2. 16_bus test system

TABLE III. LINE_DATA OF 16_BUS BALANCED SYSTEM, PU

Bus nl	Bus nr	R	X
1	4	0.012453	0.012453
4	5	0.006413	0.004608
5	6	0.006501	0.004608
6	7	0.001224	0.000405
4	8	0.00443	0.001464
8	9	0.003372	0.004439
8	10	0.001166	0.003853
10	11	0.002809	0.00192
11	12	0.00316	0.00161
11	13	0.005592	0.004415
13	2	0.003113	0.003113
10	14	0.00307	0.001564
14	15	0.004558	0.003574
14	16	0.001021	0.000974
16	3	0.003113	0.003113

TABLE IV. BUS_DATA OF 16_BUS SYSTEM, PU

Bus number	Load		Generator				Exponent of Loads	
	P	Q	Kdi	VG0i	KGi	f0	Alpha	Beta
1	0.0000	0.0000	59.9880	1.00	607.2000	1	0.00	0.00
2	0.0000	0.0000	30.0030	1.00	311.7000	1	0.00	0.00
3	0.0000	0.0000	30.0000	1.00	1211.5000	1	0.00	0.00

Bus number	Load		Generator				Exponent of Loads	
	P	Q	Kdi	VG0i	KGi	f0	Alpha	Beta
4	0.0600	0.0200	0.0000	0.00	0.0000	1	2.00	2.00
5	0.2000	0.1000	0.0000	0.00	0.0000	1	2.00	2.00
6	0.2000	0.1000	0.0000	0.00	0.0000	1	2.00	2.00
7	0.0450	0.0300	0.0000	0.00	0.0000	1	2.00	2.00
8	0.0600	0.0350	0.0000	0.00	0.0000	1	2.00	2.00
9	0.0600	0.0200	0.0000	0.00	0.0000	1	2.00	2.00
10	0.0600	0.0200	0.0000	0.00	0.0000	1	2.00	2.00
11	0.1200	0.0800	0.0000	0.00	0.0000	1	2.00	2.00
12	0.0600	0.0100	0.0000	0.00	0.0000	1	2.00	2.00
13	0.0600	0.0200	0.0000	0.00	0.0000	1	2.00	2.00
14	0.0900	0.0400	0.0000	0.00	0.0000	1	2.00	2.00
15	0.4200	0.2000	0.0000	0.00	0.0000	1	2.00	2.00
16	0.4200	0.2000	0.0000	0.00	0.0000	1	2.00	2.00

I.1.3. 38_bus test system

TABLE V. LINE_DATA OF 38_BUS BALANCED SYSTEM, PU

Bus nl	Bus nr	R	X
6	35	0.000574	0.000293
35	36	0.00307	0.001564
36	37	0.002279	0.001161
37	38	0.002373	0.001209
38	34	0.0051	0.004402

Bus nl	**Bus nr**	**R**	**X**
34	7	0.001166	0.003853
7	8	0.00443	0.001464
8	9	0.006413	0.004608
9	10	0.006501	0.004608
10	11	0.001224	0.000405
11	12	0.002331	0.000771
3	13	0.009141	0.007192
13	14	0.003372	0.004439
14	15	0.00368	0.003275
15	16	0.004647	0.003394
16	17	0.008026	0.010716
17	18	0.004558	0.003574
35	19	0.001021	0.000974
19	20	0.009366	0.00844
20	21	0.00255	0.002979
21	22	0.004414	0.005836
36	23	0.002809	0.00192
23	24	0.005592	0.004415
24	25	0.005579	0.004366
34	26	0.001264	0.000644
26	27	0.00177	0.000901
27	28	0.006594	0.005814
28	29	0.005007	0.004362

Bus nl	Bus nr	R	X
29	30	0.00316	0.00161
30	31	0.006067	0.005996
31	32	0.001933	0.002253
32	33	0.002123	0.003301
8	1	0.012453	0.012453
29	2	0.012453	0.012453
12	3	0.012453	0.012453
22	4	0.003113	0.003113
25	5	0.003113	0.003113

TABLE VI. BUS_DATA OF 38_BUS SYSTEM, PU

Bus number	Load		Generator				Exponent of Loads	
	P	Q	Kdi	VG0i	KGi	f0	Alpha	Beta
1	0.0000	0.0000	59.9880	1.01	394.0497	1	0.00	0.00
2	0.0000	0.0000	30.0030	1.01	294.0497	1	0.00	0.00
3	0.0000	0.0000	30.0000	1.01	214.0497	1	0.00	0.00
4	0.0000	0.0000	20.0000	1.01	214.0497	1	0.00	0.00
5	0.0000	0.0000	40.0000	1.01	294.0497	1	0.00	0.00
6	0.0000	0.0000	0.0000	0.00	0.0000	1	1.51	3.40
7	0.2000	0.1000	0.0000	0.00	0.0000	1	1.51	3.40
8	0.2000	0.1000	0.0000	0.00	0.0000	1	1.51	3.40
9	0.0600	0.0200	0.0000	0.00	0.0000	1	0.18	6.00
10	0.0600	0.0200	0.0000	0.00	0.0000	1	1.51	3.40

Bus number	Load		Generator				Exponent of Loads	
	P	**Q**	**Kdi**	**VG0i**	**KGi**	**f0**	**Alpha**	**Beta**
11	0.0450	0.0300	0.0000	0.00	0.0000	1	1.51	3.40
12	0.0600	0.0350	0.0000	0.00	0.0000	1	0.92	4.04
13	0.0600	0.0350	0.0000	0.00	0.0000	1	1.51	3.40
14	0.1200	0.0800	0.0000	0.00	0.0000	1	0.92	4.04
15	0.0600	0.0100	0.0000	0.00	0.0000	1	1.51	3.40
16	0.0600	0.0200	0.0000	0.00	0.0000	1	0.18	6.00
17	0.0600	0.0200	0.0000	0.00	0.0000	1	1.51	3.40
18	0.0900	0.0400	0.0000	0.00	0.0000	1	0.18	6.00
19	0.0900	0.0400	0.0000	0.00	0.0000	1	0.92	4.04
20	0.0900	0.0400	0.0000	0.00	0.0000	1	1.51	3.40
21	0.0900	0.0400	0.0000	0.00	0.0000	1	0.18	6.00
22	0.0900	0.0400	0.0000	0.00	0.0000	1	0.92	4.04
23	0.0900	0.0500	0.0000	0.00	0.0000	1	1.51	3.40
24	0.4200	0.2000	0.0000	0.00	0.0000	1	1.51	3.40
25	0.4200	0.2000	0.0000	0.00	0.0000	1	1.51	3.40
26	0.0600	0.0250	0.0000	0.00	0.0000	1	1.51	3.40
27	0.0600	0.0250	0.0000	0.00	0.0000	1	0.18	6.00
28	0.0600	0.0200	0.0000	0.00	0.0000	1	1.51	3.40
29	0.1200	0.0700	0.0000	0.00	0.0000	1	1.51	3.40
30	0.2000	0.6000	0.0000	0.00	0.0000	1	1.51	3.40
31	0.1500	0.0700	0.0000	0.00	0.0000	1	0.92	4.04
32	0.2100	0.1000	0.0000	0.00	0.0000	1	0.92	4.04

Bus number	Load		Generator				Exponent of Loads	
	P	Q	Kdi	VG0i	KGi	f0	Alpha	Beta
33	0.0600	0.0400	0.0000	0.00	0.0000	1	1.51	3.40
34	0.0600	0.0200	0.0000	0.00	0.0000	1	0.18	6.00
35	0.1000	0.0600	0.0000	0.00	0.0000	1	0.92	4.04
36	0.0900	0.0400	0.0000	0.00	0.0000	1	0.18	6.00
37	0.1200	0.0800	0.0000	0.00	0.0000	1	1.51	3.40
38	0.0600	0.0300	0.0000	0.00	0.0000	1	0.92	4.04

I.2. Three phase unbalanced system

I.2.1. Data of 25_bus test system

TABLE VII. LINE DATA OF 25_BUS SYSTEM, IMPEDANCE FOR DIFERENT TYPE OF CONDUCTOR ARE SHOWN BELOW THIS TABLE

Bus nl	Bus nr	Length, ft	Length, mile	Conductor type
1	2	1000	0.18939394	1
2	3	500	0.09469697	1
2	6	500	0.09469697	2
3	4	500	0.09469697	1
3	18	500	0.09469697	2
4	5	500	0.09469697	2
4	23	400	0.07575758	2
6	7	500	0.09469697	2
6	8	1000	0.18939394	2
7	9	500	0.09469697	2
7	14	500	0.09469697	2
7	16	500	0.09469697	2
9	10	500	0.09469697	2
10	11	300	0.05681818	2
11	12	200	0.03787879	2
11	13	200	0.03787879	2
14	15	300	0.05681818	2
14	17	300	0.05681818	2
18	20	500	0.09469697	2

Bus nl	Bus nr	Length, ft	Length, mile	Conductor type
18	21	400	0.07575758	2
20	19	400	0.07575758	2
21	22	400	0.07575758	2
23	24	400	0.07575758	2
24	25	400	0.07575758	2
5	22	400	0.07575758	2
15	8	300	0.05681818	2
12	25	500	0.09469697	3

Impedance for type 1 of conductors, ohms/mile

Z1 = [0.3686+1i*0.6852   0.0169+1i*0.1515   0.0155+1i*0.1098

0.0169+1i*0.1515   0.3757+1i*0.6715   0.0188+1i*0.2072

0.0155+1i*0.1098   0.0188+1i*0.2072   0.3723+1i*0.6782];

Impedance for type 2 of conductors, ohms/mile

Z2 = [0.9775+1i*0.8717   0.0167+1i*0.1697   0.0152+1i*0.1264

0.0167+1i*0.1697   0.9844+1i*0.8654   0.0186+1i*0.2275

0.0152+1i*0.1264   0.0186+1i*0.2275   0.9810+1i*0.8648];

Impedance for type 3 of conductors, ohms/mile

Z3 = [1.9280+1i*1.4194   0.0161+1i*0.1183   0.0161+1i*0.1183

0.0161+1i*0.1183   1.9308+1i*1.4215   0.0161+1i*0.1183

0.0161+1i*0.1183   0.0161+1i*0.1183   1.9337+1i*1.4236];

TABLE VIII. BUS DATA OF 25_BUS SYSTEM

Bus number	**Load phase A, kW**		**Load phase B, kW**		**Load phase C, kW**		**Generator**				**Exponent of Loads**	
	P	**Q**	**P**	**Q**	**P**	**Q**	**K_{di}**	**V_{0i}, pu**	**K_{Gi}**	**f0i, pu**	**α**	**β**
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.000	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.000	0.00	0.00
3	35.00	25.00	40.00	30.00	45.00	32.00	0.00	0.00	0.00	1.000	0.18	6.00
4	50.00	40.00	60.00	45.00	70.00	35.00	0.00	0.00	0.00	1.000	1.51	3.40
5	40.00	30.00	37.00	28.00	50.00	32.00	0.00	0.00	0.00	1.000	0.92	4.04
6	40.00	20.00	45.00	32.00	35.00	25.00	0.00	0.00	0.00	1.000	0.18	6.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.000	1.51	3.40
8	35.00	10.00	45.00	32.00	40.00	28.00	0.00	0.00	0.00	1.000	1.51	3.40
9	60.00	45.00	50.00	40.00	50.00	35.00	0.00	0.00	0.00	1.000	0.18	6.00
10	35.00	25.00	40.00	30.00	45.00	32.00	0.00	0.00	0.00	1.000	1.51	3.40
11	45.00	25.00	35.00	20.00	40.00	26.00	0.00	0.00	0.00	1.000	1.51	3.40
12	50.00	35.00	60.00	45.00	70.00	40.00	0.00	0.00	0.00	1.000	0.92	4.04
13	**35.00**	**25.00**	**45.00**	**32.00**	**40.00**	**30.00**	**5.00**	**1.04**	**10.00**	**1.002**	**1.51**	**3.40**
14	50.00	20.00	60.00	25.00	70.00	35.00	0.00	0.00	0.00	1.000	0.92	4.04
15	133.30	50.00	100.00	25.00	75.00	30.00	0.00	0.00	0.00	1.000	1.51	3.40

16	45.00	15.00	35.00	20.00	50.00	26.00	0.00	0.00	0.00	1.000	0.18	6.00
17	40.00	10.00	35.00	8.00	50.00	15.00	0.00	0.00	0.00	1.000	1.51	3.40
18	35.00	25.00	40.00	30.00	45.00	32.00	0.00	0.00	0.00	1.000	0.18	6.00
19	**60.00**	**45.00**	**50.00**	**35.00**	**50.00**	**40.00**	**10.00**	**1.05**	**10.00**	**1.002**	**0.92**	**4.04**
20	40.00	30.00	35.00	25.00	45.00	32.00	0.00	0.00	0.00	1.000	1.51	3.40
21	50.00	35.00	40.00	33.00	45.00	36.00	0.00	0.00	0.00	1.000	0.18	6.00
22	50.00	35.00	60.00	45.00	70.00	40.00	0.00	0.00	0.00	1.000	0.92	4.04
23	60.00	45.00	50.00	40.00	70.00	35.00	0.00	0.00	0.00	1.000	1.51	3.40
24	35.00	25.00	40.00	30.00	50.00	32.00	0.00	0.00	0.00	1.000	1.51	3.40
25	**60.00**	**45.00**	**50.00**	**30.00**	**40.00**	**35.00**	**5.00**	**1.04**	**20.00**	**1.002**	**1.51**	**3.40**

I.2.2. Changing KG13

TABLE IX. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=20

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9763	0.0000	0.0000	0.0000	0.9735	-2.0876	0.0000	0.0000	0.9739	2.0937	0.0000	0.0000
2	0.9763	0.0000	0.0000	0.0000	0.9735	-2.0876	0.0000	0.0000	0.9739	2.0937	0.0000	0.0000
3	0.9769	0.0000	0.0012	0.0007	0.9740	-2.0876	0.0013	0.0009	0.9744	2.0936	0.0015	0.0009
4	0.9771	0.0005	0.0016	0.0012	0.9742	-2.0874	0.0019	0.0014	0.9746	2.0939	0.0022	0.0011
5	0.9734	-0.0026	0.0013	0.0009	0.9702	-2.0903	0.0012	0.0008	0.9701	2.0901	0.0016	0.0009
6	0.9651	0.0038	0.0013	0.0005	0.9628	-2.0809	0.0015	0.0009	0.9643	2.1003	0.0012	0.0007
7	0.9650	0.0097	0.0000	0.0000	0.9637	-2.0743	0.0000	0.0000	0.9643	2.1069	0.0000	0.0000
8	0.9571	0.0024	0.0011	0.0003	0.9552	-2.0805	0.0014	0.0009	0.9574	2.1008	0.0012	0.0008
9	0.9778	0.0219	0.0020	0.0013	0.9773	-2.0646	0.0017	0.0012	0.9780	2.1181	0.0017	0.0010
10	0.9960	0.0339	0.0012	0.0008	0.9953	-2.0553	0.0013	0.0010	0.9956	2.1293	0.0015	0.0011
11	1.0173	0.0454	0.0015	0.0009	1.0170	-2.0466	0.0012	0.0007	1.0170	2.1404	0.0014	0.0009
12	1.0204	0.0399	0.0017	0.0013	1.0192	-2.0529	0.0020	0.0016	1.0193	2.1346	0.0024	0.0014
13	**1.0394**	**0.0624**	**0.0012**	**0.0010**	**1.0394**	**-2.0320**	**0.0016**	**0.0012**	**1.0394**	**2.1568**	**0.0014**	**0.0011**
14	0.9552	0.0047	0.0016	0.0006	0.9538	-2.0775	0.0019	0.0007	0.9545	2.1032	0.0022	0.0010

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
15	0.9514	0.0018	0.0041	0.0014	0.9513	-2.0801	0.0031	0.0010	0.9533	2.1017	0.0023	0.0011
16	0.9620	0.0084	0.0015	0.0004	0.9609	-2.0745	0.0012	0.0005	0.9607	2.1058	0.0017	0.0007
17	0.9528	0.0035	0.0012	0.0003	0.9508	-2.0772	0.0011	0.0007	0.9506	2.1025	0.0015	0.0009
18	0.9848	-0.0108	0.0012	0.0008	0.9820	-2.0999	0.0013	0.0009	0.9817	2.0833	0.0015	0.0010
19	**1.0460**	**-0.0472**	**0.0021**	**0.0018**	**1.0460**	**-2.1416**	**0.0017**	**0.0014**	**1.0460**	**2.0472**	**0.0017**	**0.0016**
20	1.0037	-0.0236	0.0013	0.0010	1.0018	-2.1151	0.0012	0.0008	1.0005	2.0721	0.0015	0.0011
21	0.9768	-0.0084	0.0017	0.0010	0.9740	-2.0965	0.0013	0.0009	0.9737	2.0850	0.0015	0.0010
22	0.9730	-0.0055	0.0016	0.0010	0.9694	-2.0933	0.0019	0.0013	0.9694	2.0869	0.0023	0.0012
23	0.9916	0.0104	0.0020	0.0015	0.9899	-2.0794	0.0016	0.0013	0.9898	2.1031	0.0023	0.0011
24	1.0114	0.0199	0.0012	0.0009	1.0103	-2.0721	0.0014	0.0010	1.0100	2.1132	0.0017	0.0011
25	**1.0343**	**0.0289**	**0.0021**	**0.0017**	**1.0343**	**-2.0655**	**0.0017**	**0.0011**	**1.0343**	**2.1233**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0212	0.0346	0.0223	0.0377	0.0377	0.1080	0.0812	0.9997	0.0075	0.9506	1.0460

TABLE X. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=20

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0150	0.0150	0.0162	0.0006	0.0009	0.0015
19	0.0078	0.0074	0.0079	0.0132	0.0136	0.0137
25	0.0152	0.0148	0.0162	0.0091	0.0094	0.0098

TABLE XI. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=30

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9751	0.0000	0.0000	0.0000	0.9720	-2.0876	0.0000	0.0000	0.9727	2.0941	0.0000	0.0000
2	0.9751	0.0000	0.0000	0.0000	0.9720	-2.0876	0.0000	0.0000	0.9727	2.0941	0.0000	0.0000
3	0.9758	-0.0002	0.0012	0.0007	0.9762	-2.0880	0.0013	0.0008	0.0973	2.0937	0.0015	0.0009
4	0.9760	0.0002	0.0016	0.0012	0.9728	-2.0876	0.0019	0.0014	0.9736	2.0940	0.0022	0.0011
5	0.9722	-0.0038	0.0013	0.0009	0.9688	-2.0915	0.0012	0.0008	0.9690	2.0893	0.0016	0.0009
6	0.9641	0.0085	0.0013	0.0005	0.9616	-2.0762	0.0015	0.0008	0.9634	2.1054	0.0012	0.0007
7	0.9642	0.0183	0.0000	0.0000	0.9627	-2.0657	0.0000	0.0000	0.9637	2.1159	0.0000	0.0000
8	0.9562	0.0081	0.0011	0.0003	0.9540	-2.0747	0.0014	0.0009	0.9565	2.1068	0.0012	0.0008
9	0.9774	0.0352	0.0020	0.0013	0.9767	-2.0512	0.0017	0.0012	0.9777	2.1318	0.0017	0.0010
10	0.9961	0.0518	0.0012	0.0008	0.9952	-2.0373	0.0013	0.0010	0.9959	2.1476	0.0015	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
11	1.0180	0.0677	0.0015	0.0009	1.0175	-2.0242	0.0012	0.0007	1.0178	2.1630	0.0014	0.0009
12	1.0203	0.0547	0.0017	0.0013	1.0188	-2.0379	0.0020	0.0016	1.0195	2.1501	0.0024	0.0014
13	**1.0419**	**0.0962**	**0.0012**	**0.0010**	**1.0419**	**-1.9982**	**0.0016**	**0.0012**	**1.0419**	**2.1906**	**0.0014**	**0.0012**
14	0.9544	0.0123	0.0016	0.0006	0.9527	-2.0698	0.0019	0.0007	0.9538	2.1112	0.0022	0.0010
15	0.9505	0.0085	0.0041	0.0014	0.9502	-2.0734	0.0031	0.0010	0.9526	2.1087	0.0023	0.0011
16	0.9612	0.0170	0.0015	0.0004	0.9599	-2.0659	0.0012	0.0005	0.9600	2.1147	0.0017	0.0007
17	0.9520	0.0111	0.0012	0.0003	0.9498	-2.0695	0.0011	0.0007	0.9499	2.1105	0.0015	0.0009
18	0.9837	-0.0151	0.0012	0.0008	0.9806	-2.1041	0.0013	0.0009	0.9807	2.0795	0.0015	0.0009
19	**1.0454**	**-0.0650**	**0.0021**	**0.0018**	**1.0454**	**-2.1594**	**0.0017**	**0.0014**	**1.0454**	**2.0294**	**0.0017**	**0.0016**
20	1.0028	-0.0328	0.0013	0.0010	1.0004	-2.1242	0.0012	0.0008	0.9998	2.0635	0.0015	0.0011
21	0.9757	-0.0117	0.0017	0.0010	0.9725	-2.0998	0.0013	0.0009	0.9727	2.0822	0.0015	0.0010
22	0.9719	-0.0078	0.0160	0.0010	0.9680	-2.0955	0.0019	0.0013	0.9684	2.0851	0.0023	0.0012
23	0.9903	0.0106	0.0020	0.0015	0.9885	-2.0792	0.0016	0.0013	.0.9886	2.1035	0.0023	0.0011
24	1.0100	0.0205	0.0012	0.0009	1.0087	-2.0714	0.0014	0.0010	1.0086	2.1139	0.0017	0.0011
25	**1.0327**	**0.0300**	**0.0021**	**0.0017**	**1.0327**	**-2.0644**	**0.0017**	**0.0011**	**1.0327**	**2.1244**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
	0.0357	0.0211	0.0346	0.0222	0.0377	0.0377	0.1080	0.0810	1.0000	0.0101	0.0973	1.0454

TABLE XII. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=30

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0192	0.0190	0.0207	-0.0034	-0.0034	-0.0026
19	0.0067	0.0064	0.0066	0.0151	0.0156	0.0157
25	0.0130	0.0126	0.0137	0.0117	0.0121	0.0125

TABLE XIII. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG25=30

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9777	0.0000	0.0000	0.0000	0.9750	-2.0876	0.0000	0.0000	0.9752	2.0934	0.0000	0.0000
2	0.9777	0.0000	0.0000	0.0000	0.9750	-2.0876	0.0000	0.0000	0.9752	2.0934	0.0000	0.0000
3	0.9783	0.0003	0.0012	0.0007	0.9755	-2.0875	0.0013	0.0009	0.9757	2.0936	0.0015	0.0009
4	0.9784	0.0011	0.0016	0.0012	0.9757	-2.0869	0.0019	0.0014	0.9758	2.0942	0.0022	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
5	0.9746	-0.0019	0.0013	0.0009	0.9716	-2.0896	0.0012	0.0008	0.9712	2.0906	0.0016	0.0009
6	0.9660	-0.0026	0.0013	0.0005	0.9638	-2.0874	0.0015	0.0009	0.9651	2.0936	0.0012	0.0007
7	0.9654	-0.0018	0.0000	0.0000	0.9642	-2.0860	0.0000	0.0000	0.9646	2.0949	0.0000	0.0000
8	0.9578	-0.0052	0.0011	0.0003	0.9560	-2.0882	0.0014	0.0009	0.9580	2.0928	0.0012	0.0008
9	0.9775	0.0040	0.0020	0.0013	0.9772	-2.0826	0.0017	0.0012	0.9775	2.0997	0.0017	0.0010
10	0.9950	0.0098	0.0012	0.0008	0.9945	-2.0794	0.0013	0.0010	0.9943	2.1047	0.0015	0.0010
11	1.0154	0.0155	0.0015	0.0009	1.0154	-2.0767	0.0012	0.0007	1.0147	2.1097	0.0014	0.0009
12	1.0204	0.0263	0.0017	0.0013	1.0199	-2.0668	0.0020	0.0016	1.0185	2.1196	0.0024	0.0014
13	**1.0346**	**0.0107**	**0.0012**	**0.0009**	**1.0346**	**-2.0837**	**0.0016**	**0.0012**	**1.0346**	**2.1051**	**0.0014**	**0.0011**
14	0.9557	-0.0055	0.0016	0.0006	0.9544	-2.0878	0.0019	0.0007	0.9548	2.0926	0.0022	0.0010
15	0.9520	-0.0071	0.0041	0.0014	0.9521	-2.0891	0.0031	0.0010	0.9538	2.0924	0.0023	0.0011
16	0.9623	-0.0031	0.0015	0.0004	0.9614	-2.0861	0.0012	0.0005	0.9609	2.0938	0.0017	0.0007
17	0.9533	-0.0067	0.0012	0.0003	0.9514	-2.0875	0.0011	0.0007	0.9510	2.0919	0.0015	0.0009
18	0.9858	-0.0099	0.0012	0.0008	0.9832	-2.0991	0.0013	0.0009	0.9827	2.0839	0.0015	0.0010
19	**1.0460**	**-0.0449**	**0.0021**	**0.0018**	**1.0460**	**-2.1393**	**0.0017**	**0.0014**	**1.0460**	**2.0495**	**0.0017**	**0.0016**
20	1.0045	-0.0222	0.0013	0.0010	1.0026	-2.1137	0.0012	0.0008	1.0012	2.0733	0.0015	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
21	0.9779	-0.0076	0.0017	0.0010	0.9752	-2.0957	0.0013	0.0009	0.9747	2.0856	0.0015	0.0010
22	0.9742	-0.0048	0.0016	0.0010	0.9707	-2.0926	0.0019	0.0013	0.9705	2.0875	0.0023	0.0012
23	0.9939	0.0165	0.0020	0.0015	0.9923	-2.0733	0.0016	0.0013	0.9920	2.1091	0.0023	0.0011
24	1.0148	0.0313	0.0012	0.0009	1.0137	-2.0606	0.0014	0.0010	1.0134	2.1246	0.0017	0.0011
25	**1.0389**	**0.0454**	**0.0021**	**0.0017**	**1.0389**	**-2.0490**	**0.0018**	**0.0011**	**1.0389**	**2.1398**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0213	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	0.9997	0.0074	0.9510	1.0460

TABLE XIV. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG25=30

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0075	0.0076	0.0080	0.0084	0.0091	0.0096
19	0.0078	0.0074	0.0079	0.0129	0.0133	0.0134
25	0.0228	0.0221	0.0244	0.0017	0.0016	0.0020

TABLE XV. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG25=40

Bus n0	**Phase A**				**Phase B**				**Phase C**			
	Van (pu,rad)		**Load (pu)**		**Vbn (pu,rad)**		**Load (pu)**		**Vcn (pu,rad)**		**Load (pu)**	
	Mag	**Agl**	**P**	**Q**	**Mag**	**Agl**	**P**	**Q**	**Mag**	**Agl**	**P**	**Q**
1	0.9776	0.0000	0.0000	0.0000	0.9748	-2.0876	0.0000	0.0000	0.9753	2.0937	0.0000	0.0000
2	0.9776	0.0000	0.0000	0.0000	0.9748	-2.0876	0.0000	0.0000	0.9753	2.0937	0.0000	0.0000
3	0.9782	0.0003	0.0012	0.0007	0.9753	-2.0875	0.0013	0.0009	0.9757	2.0939	0.0015	0.0009
4	0.9783	0.0013	0.0016	0.0012	0.9754	-2.0867	0.0019	0.0014	0.9758	2.0946	0.0022	0.0011
5	0.9744	-0.0027	0.0013	0.0009	0.9713	-2.0904	0.0012	0.0008	0.9712	2.0900	0.0016	0.0009
6	0.9658	-0.0022	0.0013	0.0005	0.9636	-2.0870	0.0015	0.0009	0.9650	2.0941	0.0012	0.0007
7	0.9652	-0.0011	0.0000	0.0000	0.9640	-2.0853	0.0000	0.0000	0.9645	2.0957	0.0000	0.0000
8	0.9577	-0.0048	0.0011	0.0003	0.9558	-2.0877	0.0014	0.0009	0.9579	2.0934	0.0012	0.0008
9	0.9773	0.0050	0.0020	0.0013	0.9770	-2.0816	0.0017	0.0012	0.9773	2.1008	0.0017	0.0010
10	0.9947	0.0112	0.0012	0.0008	0.9943	-2.0780	0.0013	0.0010	0.9940	2.1060	0.0015	0.0010
11	1.0151	0.0172	0.0015	0.0009	1.0152	-2.0749	0.0012	0.0007	1.0143	2.1114	0.0014	0.0009
12	1.0206	0.0319	0.0017	0.0013	1.0203	-2.0613	0.0020	0.0016	1.0186	2.1249	0.0024	0.0014
13	**1.0338**	**0.0090**	**0.0012**	**0.0009**	**1.0338**	**-2.0854**	**0.0016**	**0.0012**	**1.0338**	**2.1034**	**0.0014**	**0.0011**
14	0.9556	-0.0050	0.0016	0.0006	0.9542	-2.0872	0.0019	0.0007	0.9547	2.0933	0.0022	0.0010
15	0.9518	-0.0066	0.0041	0.0014	0.9519	-2.0885	0.0031	0.0010	0.9537	2.0930	0.0023	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
16	0.9622	-0.0025	0.0015	0.0004	0.9612	-2.0855	0.0012	0.0005	0.9608	2.0946	0.0017	0.0007
17	0.9532	-0.0062	0.0012	0.0003	0.9512	-2.0869	0.0011	0.0007	0.9509	2.0926	0.0015	0.0009
18	0.9856	-0.0137	0.0012	0.0008	0.9827	-2.1027	0.0013	0.0009	0.9826	2.0806	0.0015	0.0010
19	**1.0455**	**-0.0613**	**0.0021**	**0.0018**	**1.0455**	**-2.1557**	**0.0017**	**0.0014**	**1.0455**	**2.0331**	**0.0017**	**0.0016**
20	1.0041	-0.0305	0.0013	0.0010	1.0019	-2.1219	0.0012	0.0008	1.0011	2.0655	0.0015	0.0011
21	0.9777	-0.0104	0.0017	0.0010	0.9748	-2.0985	0.0013	0.0009	0.9746	2.0831	0.0015	0.0010
22	0.9740	-0.0066	0.0016	0.0010	0.9703	-2.0943	0.0019	0.0013	0.9704	2.0860	0.0023	0.0012
23	0.9942	0.0210	0.0020	0.0015	0.9926	-2.0687	0.0016	0.0013	0.9924	2.1137	0.0023	0.0011
24	1.0157	0.0400	0.0012	0.0009	1.0146	-2.0520	0.0014	0.0011	1.0143	2.1333	0.0017	0.0011
25	**1.0406**	**0.0580**	**0.0021**	**0.0017**	**1.0406**	**-2.0364**	**0.0018**	**0.0011**	**1.0406**	**2.1524**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0213	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	1.0000	0.0090	0.9509	1.0455

TABLE XVI. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG25=40

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0063	0.0065	0.0067	0.0096	0.0104	0.0109
19	0.0066	0.0063	0.0066	0.0146	0.0151	0.0152
25	0.0257	0.0249	0.0275	-0.0010	-0.0012	-0.0007

TABLE XVII. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=15 AND KG19=15

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1.0000	0.9769	-0.0000	0.0000	0.0000	0.0975	-2.0878	0.0000	0.0000	0.9741	2.0927	0.0000	0.0000
2.0000	0.9769	0.0000	0.0000	0.0000	0.0975	-2.0878	0.0000	0.0000	0.9741	2.0927	0.0000	0.0000
3.0000	0.9774	0.0004	0.0012	0.0007	0.9750	-2.0876	0.0013	0.0009	0.9745	2.0929	0.0015	0.0009
4.0000	0.9777	0.0007	0.0016	0.0012	0.9753	-2.0874	0.0019	0.0014	0.9748	2.0931	0.0022	0.0011
5.0000	0.9740	0.0004	0.0013	0.0009	0.9714	-2.0874	0.0012	0.0008	0.9703	2.0921	0.0016	0.0009
6.0000	0.9654	-0.0035	0.0013	0.0005	0.9635	-2.0884	0.0015	0.0009	0.9643	2.0921	0.0012	0.0007
7.0000	0.9651	-0.0035	0.0000	0.0000	0.9640	-2.0877	0.0000	0.0000	0.9641	2.0929	0.0000	0.0000
8.0000	0.9574	-0.0064	0.0011	0.0003	0.9558	-2.0894	0.0014	0.0009	0.9573	2.0912	0.0012	0.0008

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
9.0000	0.9775	0.0013	0.0020	0.0013	0.9772	-2.0853	0.0017	0.0012	0.9775	2.0969	0.0070	0.0010
10.0000	0.9952	0.0062	0.0012	0.0008	0.9946	-2.0830	0.0013	0.0010	0.9946	2.1012	0.0015	0.0010
11.0000	1.0158	0.0110	0.0015	0.0009	1.0157	-2.0811	0.0012	0.0007	1.0153	2.1056	0.0014	0.0009
12.0000	1.0194	0.0108	0.0017	0.0013	1.0184	-2.0821	0.0020	0.0016	1.0180	2.1050	0.0024	0.0014
13.0000	**1.0367**	**0.0162**	**0.0012**	**0.0009**	**1.0367**	**-2.0782**	**0.0016**	**0.0012**	**1.0367**	**2.1106**	**0.0014**	**0.0011**
14.0000	0.9554	-0.0071	0.0016	0.0006	0.9542	-2.0894	0.0019	0.0007	0.9543	2.0907	0.0022	0.0010
15.0000	0.9516	-0.0084	0.0041	0.0014	0.9519	-2.0905	0.0031	0.0010	0.9532	2.0906	0.0023	0.0011
16.0000	0.9620	-0.0049	0.0015	0.0004	0.9612	-2.0879	0.0012	0.0005	0.9605	2.0918	0.0017	0.0007
17.0000	0.9530	-0.0083	0.0012	0.0003	0.9612	-2.0891	0.0011	0.0007	0.9505	2.0900	0.0015	0.0009
18.0000	0.9855	0.0006	0.0012	0.0008	0.9835	-2.0887	0.0013	0.0009	0.9819	2.0935	0.0015	0.0010
19.0000	**1.0475**	**0.0015**	**0.0021**	**0.0018**	**1.0475**	**-2.0929**	**0.0017**	**0.0014**	**1.0475**	**2.0959**	**0.0017**	**0.0016**
20.0000	1.0047	0.0014	0.0013	0.0010	1.0037	-2.0904	0.0012	0.0008	1.0008	2.0954	0.0015	0.0011
21.0000	0.9775	0.0003	0.0017	0.0010	0.9754	-2.0881	0.0013	0.0009	0.9737	2.0925	0.0015	0.0010
22.0000	0.9737	0.0003	0.0016	0.0010	0.9707	-2.0877	0.0019	0.0013	0.9696	2.0916	0.0023	0.0012
23.0000	0.9920	0.0039	0.0020	0.0015	0.9906	-2.0860	0.0016	0.0030	0.9899	2.0959	0.0023	0.0011
24.0000	1.0116	0.0069	0.0012	0.0009	1.0105	-2.0851	0.0014	0.0010	1.0101	2.0999	0.0017	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
25.0000	**1.0341**	**0.0097**	**0.0021**	**0.0017**	**1.0341**	**-2.0847**	**0.0017**	**0.0011**	**1.0341**	**2.1041**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0212	0.0346	0.0223	0.0377	0.0377	0.1080	0.0812	0.9997	0.0055	0.0975	1.0475

TABLE XVIII. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=15 AND KG19=15

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0110	0.1110	0.0119	0.0049	0.0054	0.0060
19	0.0114	0.0101	0.0118	0.0081	0.0083	0.0084
25	0.0150	0.0145	0.0159	0.0094	0.0097	0.0101

TABLE XIX. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=15 AND KG19=20

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9763	-0.0000	0.0000	0.0000	0.9742	-2.0879	0.0000	0.0000	0.9733	2.0922	0.0000	0.0000
2	0.9763	0.0000	0.0000	0.0000	0.9742	-2.0879	0.0000	0.0000	0.9733	2.0922	0.0000	0.0000
3	0.9768	0.0005	0.0012	0.0007	0.9747	-2.0875	0.0013	0.0009	0.9737	2.0925	0.0015	0.0009

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
4	0.9771	0.0007	0.0016	0.0012	0.9750	-2.0875	0.0019	0.0014	0.9740	2.0925	0.0022	0.0011
5	0.9734	0.0022	0.0013	0.0009	0.9711	-2.0858	0.0012	0.0008	0.9695	2.0932	0.0016	0.0009
6	0.9648	-0.0069	0.0013	0.0005	0.9631	-2.0919	0.0015	0.0009	0.9636	2.0883	0.0012	0.0007
7	0.9644	-0.0096	0.0000	0.0000	0.9636	-2.0939	0.0000	0.0000	0.9634	2.0864	0.0000	0.0000
8	0.9567	-0.0104	0.0011	0.0003	0.9554	-2.0935	0.0014	0.0009	0.9566	2.0867	0.0012	0.0008
9	0.9768	-0.0081	0.0020	0.0013	0.9766	-2.0948	0.0017	0.0012	0.9767	2.0872	0.0017	0.0010
10	0.9944	0.0064	0.0012	0.0008	0.9940	-2.0957	0.0013	0.0010	0.9938	2.0884	0.0015	0.0010
11	1.0150	-0.0048	0.0015	0.0009	1.0149	-2.0968	0.0012	0.0007	1.0145	2.0898	0.0014	0.0009
12	1.0185	-0.0046	0.0017	0.0013	1.0176	-2.0975	0.0020	0.0016	1.0171	2.0895	0.0024	0.0014
13	**1.0359**	**-0.0029**	**0.0012**	**0.0009**	**1.0359**	**-2.0973**	**0.0016**	**0.0012**	**1.0359**	**2.0915**	**0.0014**	**0.0011**
14	0.9547	-0.0125	0.0016	0.0006	0.9538	-2.0949	0.0019	0.0007	0.9536	2.0849	0.0022	0.0010
15	0.9509	-0.0132	0.0041	0.0014	0.9514	-2.0953	0.0031	0.0010	0.9525	2.0854	0.0023	0.0011
16	0.9614	-0.0110	0.0015	0.0004	0.9608	-2.0941	0.0012	0.0005	0.9597	2.0853	0.0017	0.0007
17	0.9523	-0.0137	0.0012	0.0003	0.9508	-2.0946	0.0011	0.0007	0.9498	2.0842	0.0015	0.0009
18	0.9851	0.0075	0.0012	0.0008	0.9835	-2.0820	0.0013	0.0009	0.9811	2.0996	0.0015	0.0010
19	**1.0484**	**0.0309**	**0.0021**	**0.0018**	**1.0484**	**-2.0635**	**0.0017**	**0.0014**	**1.0484**	**2.1253**	**0.0017**	**0.0016**

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	**Agl**	**P**	**Q**	**Mag**	**Agl**	**P**	**Q**	**Mag**	**Agl**	**P**	**Q**
20	1.0044	0.0164	0.0013	0.0010	1.0041	-2.0756	0.0012	0.0008	1.0002	2.1094	0.0015	0.0011
21	0.9770	0.0054	0.0017	0.0010	0.9753	-2.0830	0.0013	0.0009	0.9731	2.0969	0.0015	0.0010
22	0.9731	0.0038	0.0016	0.0010	0.9705	-2.0843	0.0019	0.0013	0.9688	2.0944	0.0023	0.0012
23	0.9913	-0.0012	0.0020	0.0015	0.9901	-2.0912	0.0016	0.0013	0.9891	2.0905	0.0023	0.0011
24	1.0107	-0.0030	0.0012	0.0009	1.0098	-2.0951	0.0014	0.0010	1.0092	2.0898	0.0017	0.0011
25	**1.0332**	**-0.0049**	**0.0021**	**0.0017**	**1.0332**	**-2.0993**	**0.0017**	**0.0011**	**1.0332**	**2.0895**	**0.0014**	**13.0000**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0212	0.0346	0.0223	0.0377	0.0377	0.1080	0.0811	0.9999	0.0058	0.9498	1.0484

TABLE XX. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=15 AND KG19=20

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0100	0.0102	0.0108	0.0062	0.0068	0.0074
19	0.0138	0.0131	0.0144	0.0052	0.0052	0.0053
25	0.0136	0.0132	0.0145	0.0111	0.0114	0.0117

TABLE XXI. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=17 AND KG19=20

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9763	0.0000	0.0000	0.0000	0.9742	-2.0879	0.0000	0.0000	0.9734	2.0923	0.0000	0.0000
2	0.9763	0.0000	0.0000	0.0000	0.9742	-2.0879	0.0000	0.0000	0.9734	2.0923	0.0000	0.0000
3	0.9768	0.0005	0.0012	0.0007	0.9747	-2.0876	0.0013	0.0009	0.9738	2.0926	0.0015	0.0009
4	0.9771	0.0006	0.0016	0.0012	0.9749	-2.0876	0.0019	0.0014	0.9741	2.0926	0.0022	0.0011
5	0.9734	0.0017	0.0013	0.0009	0.9711	-2.0862	0.0012	0.0008	0.9696	2.0929	0.0016	0.0009
6	0.9649	-0.0056	0.0013	0.0005	0.9632	-2.0905	0.0015	0.0009	0.9637	2.0897	0.0012	0.0007
7	0.9646	-0.0073	0.0000	0.0000	0.9637	-2.0915	0.0000	0.0000	0.9636	2.0889	0.0000	0.0000
8	0.9568	-0.0089	0.0011	0.0003	0.9554	-2.0920	0.0014	0.0009	0.9567	2.0883	0.0012	0.0008
9	0.9770	-0.0045	0.0020	0.0013	0.9768	-2.0911	0.0017	0.0012	0.9769	2.0910	0.0017	0.0010
10	0.9947	-0.0015	0.0012	0.0008	0.9942	-2.0908	0.0013	0.0010	0.9941	2.0934	0.0015	0.0010
11	1.0154	0.0013	0.0015	0.0009	1.0152	-2.0907	0.0012	0.0007	1.0149	2.0960	0.0014	0.0009
12	1.0187	-0.0002	0.0017	0.0013	1.0177	-2.0930	0.0020	0.0016	1.0173	2.0941	0.0024	0.0014
13	**1.0366**	**0.0061**	**0.0012**	**0.0009**	**1.0366**	**-2.0883**	**0.0016**	**0.0012**	**1.0366**	**2.1005**	**0.0014**	**0.0011**
14	0.9548	-0.0104	0.0016	0.0006	0.9538	-2.0928	0.0019	0.0007	0.9537	2.0871	0.0022	0.0010
15	0.9510	-0.0113	0.0041	0.0014	0.9515	-2.0934	0.0031	0.0010	0.9526	2.0874	0.0023	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
16	0.9615	-0.0086	0.0015	0.0004	0.9609	-2.0917	0.0012	0.0005	0.9599	2.0878	0.0017	0.0007
17	0.9525	-0.0116	0.0012	0.0003	0.9509	-2.0925	0.0011	0.0007	0.9499	2.0864	0.0015	0.0009
18	0.9851	0.0061	0.0012	0.0008	0.9834	-2.0834	0.0013	0.0009	0.9812	2.0983	0.0015	0.0010
19	**1.0482**	**0.0249**	**0.0021**	**0.0018**	**1.0482**	**-2.0695**	**0.0017**	**0.0014**	**1.0482**	**2.1193**	**0.0017**	**0.0016**
20	1.0044	0.0133	0.0013	0.0010	1.0040	-2.0787	0.0012	0.0008	1.0003	2.1066	0.0015	0.0011
21	0.9770	0.0043	0.0017	0.0010	0.9752	-2.0841	0.0013	0.0009	0.9732	2.0960	0.0015	0.0010
22	0.9732	0.0030	0.0016	0.0010	0.9705	-2.0851	0.0019	0.0013	0.9689	2.0938	0.0023	0.0012
23	0.9912	-0.0008	0.0020	0.0015	0.9900	-2.0908	0.0016	0.0013	0.9890	2.0910	0.0023	0.0011
24	1.0106	-0.0022	0.0012	0.0009	1.0096	-2.0943	0.0014	0.0010	1.0090	2.0906	0.0017	0.0011
25	**1.0329**	**-0.0037**	**0.0021**	**0.0017**	**1.0329**	**-2.0981**	**0.0017**	**0.0011**	**1.0329**	**2.0907**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0212	0.0346	0.0223	0.0377	0.0377	0.1080	0.0811	1.0000	0.0057	0.9499	1.0482

TABLE XXII. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=17 AND KG19=20

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0110	0.0111	0.0118	0.0052	0.0057	0.0063
19	0.0133	0.0126	0.0139	0.0058	0.0059	0.0060
25	0.0132	0.0128	0.0140	0.0115	0.0119	0.0122

TABLE XXIII. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=10 AND F025=1.003

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9777	0.0000	0.0000	0.0000	0.9750	-2.0877	0.0000	0.0000	0.9752	2.0934	0.0000	0.0000
2	0.9777	0.0000	0.0000	0.0000	0.9750	-2.0877	0.0000	0.0000	0.9752	2.0934	0.0000	0.0000
3	0.9782	0.0003	0.0012	0.0007	0.9755	-2.0875	0.0013	0.0009	0.9757	2.0936	0.0015	0.0009
4	0.9784	0.0011	0.0016	0.0012	0.9757	-2.0869	0.0019	0.0014	0.9758	2.0942	0.0022	0.0011
5	0.9746	-0.0017	0.0013	0.0009	0.9716	-2.0895	0.0012	0.0008	0.9712	2.0907	0.0016	0.0009
6	0.9660	-0.0026	0.0013	0.0005	0.9639	-2.0874	0.0015	0.0009	0.9651	2.0935	0.0012	0.0007
7	0.9654	-0.0019	0.0000	0.0000	0.9642	-2.0861	0.0000	0.0000	0.9646	2.0948	0.0000	0.0000
8	0.9579	-0.0053	0.0011	0.0003	0.9561	-2.0883	0.0014	0.0009	0.9580	2.0927	0.0012	0.0008

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
9	0.9776	0.0038	0.0020	0.0013	0.9772	-2.0828	0.0017	0.0012	0.9775	2.0995	0.0017	0.0010
10	0.9950	0.0096	0.0012	0.0008	0.9945	-2.0797	0.0013	0.0010	0.9944	2.1044	0.0015	0.0010
11	1.0154	0.0151	0.0015	0.0009	1.0154	-2.0770	0.0012	0.0007	1.0148	2.1094	0.0014	0.0009
12	1.0204	0.0253	0.0017	0.0013	1.0199	-2.0679	0.0020	0.0016	1.0185	2.1186	0.0024	0.0014
13	**1.0347**	**0.0110**	**0.0012**	**0.0009**	**1.0347**	**-2.0834**	**0.0016**	**0.0012**	**1.0347**	**2.1054**	**0.0014**	**0.0011**
14	0.9557	-0.0057	0.0016	0.0006	0.9544	-2.0879	0.0019	0.0007	0.9548	2.0925	0.0022	0.0010
15	0.9520	-0.0072	0.0041	0.0014	0.9521	-2.0892	0.0031	0.0010	0.9538	2.0922	0.0023	0.0011
16	0.9624	-0.0033	0.0015	0.0004	0.9614	-2.0863	0.0012	0.0005	0.9609	2.0937	0.0017	0.0007
17	0.9533	-0.0069	0.0012	0.0003	0.9515	-2.0876	0.0011	0.0007	0.9510	2.0918	0.0015	0.0009
18	0.9859	-0.0092	0.0012	0.0008	0.9833	-2.0983	0.0013	0.0009	0.9827	2.0846	0.0015	0.0010
19	**1.0462**	**-0.0417**	**0.0021**	**0.0018**	**1.0462**	**-2.1361**	**0.0017**	**0.0014**	**1.0462**	**2.0527**	**0.0017**	**0.0016**
20	1.0045	-0.0206	0.0013	0.0010	1.0027	-2.1121	0.0012	0.0008	1.0013	2.0748	0.0015	0.0011
21	0.9779	-0.0070	0.0017	0.0010	0.9753	-2.0952	0.0013	0.0009	0.9747	2.0861	0.0015	0.0010
22	0.9742	-0.0044	0.0016	0.0011	0.9708	-2.0922	0.0019	0.0013	0.9705	2.0878	0.0023	0.0012
23	0.9938	0.0157	0.0020	0.0015	0.9922	-2.0741	0.0016	0.0013	0.9919	2.1082	0.0023	0.0011
24	1.0146	0.0297	0.0012	0.0009	1.0135	-2.0623	0.0014	0.0010	1.0132	2.1229	0.0017	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
25	**1.0386**	**0.0430**	**0.0021**	**0.0017**	**1.0386**	**-2.0514**	**0.0018**	**0.0011**	**1.0386**	**2.1374**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0213	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	0.9996	0.0072	0.9510	1.0462

TABLE XXIV. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=10 AND F025=1.003

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0077	0.0079	0.0083	0.0082	0.0089	0.0094
19	0.0080	0.0076	0.0081	0.0126	0.0129	0.0130
25	0.0223	0.0216	0.0238	0.0022	0.0021	0.0026

TABLE XXV. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=18 AND F025=1.003

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9768	0.0000	0.0000	0.0000	0.9739	-2.0876	0.0000	0.0000	0.9745	2.0938	0.0000	0.0000

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
2	0.9768	0.0000	0.0000	0.0000	0.9739	-2.0876	0.0000	0.0000	0.9745	2.0938	0.0000	0.0000
3	0.9774	0.0001	0.0012	0.0007	0.9745	-2.0877	0.0013	0.0009	0.9750	2.0938	0.0015	0.0009
4	0.9776	0.0008	0.0016	0.0012	0.9746	-2.0871	0.0019	0.0014	0.9751	2.0943	0.0022	0.0011
5	0.9738	-0.0031	0.0013	0.0009	0.9705	-2.0907	0.0012	0.0008	0.9705	2.0898	0.0016	0.0009
6	0.9654	0.0022	0.0013	0.0005	0.9631	-2.0825	0.0015	0.0009	0.9647	2.0988	0.0012	0.0007
7	0.9652	0.0069	0.0000	0.0000	0.9639	-2.0772	0.0000	0.0000	0.9645	2.1040	0.0000	0.0000
8	0.9574	0.0005	0.0011	0.0003	0.9554	-2.0823	0.0014	0.0009	0.9577	2.0989	0.0012	0.0008
9	0.9778	0.0175	0.0020	0.0013	0.9773	-2.0690	0.0017	0.0012	0.9779	2.1136	0.0017	0.0010
10	0.9957	0.0280	0.0012	0.0008	0.9951	-2.0612	0.0013	0.0010	0.9953	2.1232	0.0015	0.0010
11	1.0168	0.0381	0.0015	0.0009	1.0166	-2.0539	0.0012	0.0007	1.0162	2.1328	0.0014	0.0009
12	1.0209	0.0406	0.0017	0.0013	1.0201	-2.0523	0.0020	0.0016	1.0194	2.1347	0.0024	0.0014
13	**1.0374**	**0.0458**	**0.0012**	**0.0009**	**1.0374**	**-2.0485**	**0.0016**	**0.0012**	**1.0374**	**2.1402**	**0.0014**	**0.0011**
14	0.9555	0.0022	0.0016	0.0006	0.9540	-2.0800	0.0019	0.0007	0.9547	2.1007	0.0022	0.0010
15	0.9516	-0.0003	0.0041	0.0014	0.9516	-2.0822	0.0031	0.0010	0.9536	2.0995	0.0023	0.0011
16	0.9622	0.0056	0.0015	0.0004	0.9611	-2.0774	0.0012	0.0005	0.9608	2.1029	0.0017	0.0007
17	0.9531	0.0010	0.0012	0.0003	0.9510	-2.0797	0.0011	0.0007	0.9509	2.1000	0.0015	0.0009

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
18	0.9850	-0.0137	0.0012	0.0008	0.9821	-2.1028	0.0013	0.0009	0.9820	2.0806	0.0015	0.0010
19	**1.0455**	**-0.0605**	**0.0021**	**0.0018**	**1.0455**	**-2.1549**	**0.0017**	**0.0014**	**1.0455**	**2.0339**	**0.0017**	**0.0016**
20	1.0037	-0.0303	0.0013	0.0010	1.0015	-2.1217	0.0012	0.0008	1.0007	2.0658	0.0015	0.0011
21	0.9771	-0.0105	0.0017	0.0010	0.9741	-2.0986	0.0013	0.0009	0.9740	2.0831	0.0015	0.0010
22	0.9733	-0.0068	0.0016	0.0010	0.9696	-2.0946	0.0019	0.0013	0.9698	2.0858	0.0023	0.0012
23	0.9927	0.0160	0.0020	0.0015	0.9910	-2.0738	0.0016	0.0013	0.9909	2.1088	0.0023	0.0011
24	1.0133	0.0306	0.0012	0.0009	1.0122	-2.0614	0.0014	0.0010	1.0119	2.1239	0.0017	0.0011
25	**1.0371**	**0.0445**	**0.0021**	**0.0017**	**1.0371**	**-2.0499**	**0.0018**	**0.0011**	**1.0371**	**2.1389**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0212	0.0346	0.0223	0.0377	0.0377	0.1081	0.0812	1.0000	0.0079	0.9509	1.0455

TABLE XXVI. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=18 AND F025=1.003

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0117	0.0117	0.0126	0.0039	0.0043	0.0049
19	0.0068	0.0064	0.0068	0.0146	0.0150	0.0151
25	0.0198	0.0192	0.0211	0.0046	0.0047	0.0051

TABLE XXVII. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=10 AND F025=1.0035

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9777	0.0000	0.0000	0.0000	0.9749	-2.0876	0.0000	0.0000	0.9753	2.0936	0.0000	0.0000
2	0.9777	0.0000	0.0000	0.0000	0.9749	-2.0876	0.0000	0.0000	0.9753	2.0936	0.0000	0.0000
3	0.9783	0.0003	0.0012	0.0007	0.9754	-2.0875	0.0013	0.0009	0.9757	2.0937	0.0015	0.0009
4	0.9784	0.0012	0.0016	0.0012	0.9756	-2.0868	0.0019	0.0014	0.9758	2.0944	0.0022	0.0011
5	0.9745	-0.0022	0.0013	0.0009	0.9715	-2.0899	0.0012	0.0008	0.9712	2.0903	0.0016	0.0009
6	0.9659	-0.0024	0.0013	0.0005	0.9638	-2.0872	0.0015	0.0009	0.9651	2.0938	0.0012	0.0007
7	0.9653	-0.0015	0.0000	0.0000	0.9641	-2.0857	0.0000	0.0000	0.9645	2.0953	0.0000	0.0000
8	0.9578	-0.0050	0.0011	0.0003	0.9560	-2.0880	0.0014	0.0009	0.9580	2.0930	0.0012	0.0008
9	0.9774	0.0044	0.0020	0.0013	0.9771	-2.0822	0.0017	0.0012	0.9775	2.1001	0.0017	0.0010
10	0.9949	0.0104	0.0012	0.0008	0.9944	-2.0788	0.0013	0.0010	0.9942	2.1052	0.0015	0.0010
11	1.0153	0.0162	0.0015	0.0009	1.0153	-2.0759	0.0012	0.0007	1.0145	2.1104	0.0014	0.0009
12	1.0205	0.0288	0.0017	0.0013	1.0201	-2.0644	0.0020	0.0016	1.0185	2.1219	0.0024	0.0014
13	**1.0342**	**0.0099**	**0.0012**	**0.0009**	**1.0342**	**-2.0845**	**0.0016**	**0.0012**	**1.0342**	**2.1043**	**0.0014**	**0.0011**
14	0.9557	-0.0053	0.0016	0.0006	0.9543	-2.0875	0.0019	0.0007	0.9548	2.0929	0.0022	0.0010
15	0.9519	-0.0069	0.0041	0.0014	0.9520	-2.0888	0.0031	0.0010	0.9538	2.0927	0.0023	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
16	0.9623	-0.0029	0.0015	0.0004	0.9613	-2.0859	0.0012	0.0005	0.9609	2.0942	0.0017	0.0007
17	0.9533	-0.0065	0.0012	0.0003	0.9514	-2.0872	0.0011	0.0007	0.9510	2.0922	0.0015	0.0009
18	0.9858	-0.0116	0.0012	0.0008	0.9830	-2.1007	0.0013	0.0009	0.9827	2.0825	0.0015	0.0010
19	**1.0458**	**-0.0520**	**0.0021**	**0.0018**	**1.0458**	**-2.1464**	**0.0017**	**0.0014**	**1.0458**	**2.0424**	**0.0017**	**0.0016**
20	1.0043	-0.0258	0.0013	0.0010	1.0023	-2.1172	0.0012	0.0008	1.0012	2.0699	0.0015	0.0011
21	0.9778	-0.0088	0.0017	0.0010	0.9751	-2.0969	0.0013	0.0009	0.9747	2.0845	0.0015	0.0010
22	0.9741	-0.0055	0.0016	0.0010	0.9706	-2.0933	0.0019	0.0013	0.9705	2.0868	0.0023	0.0012
23	0.9940	0.0185	0.0020	0.0015	0.9924	-2.0713	0.0016	0.0013	0.9922	2.1111	0.0023	0.0011
24	1.0152	0.0351	0.0012	0.0009	1.0141	-2.0569	0.0014	0.0010	1.0138	2.1283	0.0017	0.0011
25	**1.0397**	**0.0509**	**0.0021**	**0.0017**	**1.0397**	**-2.0435**	**0.0018**	**0.0011**	**1.0397**	**2.1453**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0213	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	0.9998	0.0080	0.9510	1.0458

TABLE XXVIII. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=10 AND F025=1.0035

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0069	0.0071	0.0074	0.0089	0.0097	0.0102
19	0.0073	0.0069	0.0073	0.0136	0.0141	0.0141
25	0.0241	0.0233	0.0257	0.0005	0.0003	0.0008

TABLE XXIX. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG13=13 AND F025=1.0035

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9774	0.0000	0.0000	0.0000	0.9745	-2.0876	0.0000	0.0000	0.9750	2.0937	0.0000	0.0000
2	0.9774	0.0000	0.0000	0.0000	0.9745	-2.0876	0.0000	0.0000	0.9750	2.0937	0.0000	0.0000
3	0.9780	0.0002	0.0012	0.0007	0.9751	-2.0875	0.0013	0.0009	0.9755	2.0938	0.0015	0.0009
4	0.9781	0.0011	0.0016	0.0012	0.9752	-2.0868	0.0019	0.0014	0.9756	2.0945	0.0022	0.0011
5	0.9742	-0.0027	0.0013	0.0009	0.9710	-2.0904	0.0012	0.0008	0.9710	2.0900	0.0016	0.0009
6	0.9658	-0.0005	0.0013	0.0005	0.9635	-2.0853	0.0015	0.0009	0.9650	2.0958	0.0012	0.0007
7	0.9653	0.0019	0.0000	0.0000	0.9640	-2.0823	0.0000	0.0000	0.9646	2.0988	0.0000	0.0000
8	0.9577	-0.0028	0.0011	0.0003	0.9558	-2.0857	0.0014	0.0009	0.9579	2.0954	0.0012	0.0008

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
9	0.9776	0.0097	0.0020	0.0013	0.9772	-2.0769	0.0017	0.0012	0.9777	2.1055	0.0017	0.0010
10	0.9952	0.0175	0.0012	0.0008	0.9947	-2.0718	0.0013	0.0010	0.9946	2.1124	0.0015	0.0010
11	1.0158	0.0250	0.0015	0.0009	1.0158	-2.0671	0.0012	0.0007	1.0152	2.1194	0.0014	0.0009
12	1.0208	0.0347	0.0017	0.0013	1.0203	-2.0585	0.0020	0.0016	1.0190	2.1281	0.0024	0.0014
13	**1.0353**	**0.0233**	**0.0012**	**0.0009**	**1.0353**	**-2.0711**	**0.0016**	**0.0012**	**1.0353**	**2.1177**	**0.0014**	**0.0011**
14	0.9556	-0.0023	0.0016	0.0006	0.9542	-2.0845	0.0019	0.0007	0.9548	2.0961	0.0022	0.0010
15	0.9518	-0.0043	0.0041	0.0014	0.9518	-2.0862	0.0031	0.0010	0.9538	2.0954	0.0023	0.0011
16	0.9623	0.0005	0.0015	0.0004	0.9612	-2.0824	0.0012	0.0005	0.9609	2.0977	0.0017	0.0007
17	0.9532	-0.0035	0.0012	0.0003	0.9512	-2.0842	0.0011	0.0007	0.9510	2.0954	0.0015	0.0009
18	0.9854	-0.0133	0.0012	0.0008	0.9826	-2.1024	0.0013	0.0009	0.9824	2.0809	0.0015	0.0010
19	**1.0456**	**-0.0593**	**0.0021**	**0.0018**	**1.0456**	**-2.1537**	**0.0017**	**0.0014**	**1.0456**	**2.0351**	**0.0017**	**0.0016**
20	1.0040	-0.0295	0.0013	0.0010	1.0018	-2.1210	0.0012	0.0008	1.0010	2.0664	0.0015	0.0011
21	0.9775	-0.0101	0.0017	0.0010	0.9746	-2.0982	0.0013	0.0009	0.9745	2.0834	0.0015	0.0010
22	0.9738	-0.0065	0.0016	0.0010	0.9701	-2.0942	0.0019	0.0013	0.9702	2.0861	0.0023	0.0012
23	0.9936	0.0186	0.0020	0.0015	0.9920	-2.0711	0.0016	0.0013	0.9918	2.1114	0.0023	0.0011
24	1.0147	0.0355	0.0012	0.0009	1.0136	-2.0565	0.0014	0.0010	1.0133	2.1288	0.0017	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
25	**1.0391**	**0.0515**	**0.0021**	**0.0017**	**1.0391**	**-2.0429**	**0.0018**	**0.0011**	**1.0391**	**2.1459**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0213	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	1.0000	0.0082	0.9510	1.0456

TABLE XXX. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG13=13 AND F025=1.0035

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0084	0.0086	0.0091	0.0073	0.0079	0.0084
19	0.0068	0.0065	0.0068	0.0144	0.0149	0.0150
25	0.0231	0.0224	0.0246	0.0014	0.0013	0.0018

TABLE XXXI. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG19=15 AND F025=1.003

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9778	0.0000	0.0000	0.0000	0.9754	-2.0878	0.0000	0.0000	0.9750	2.0928	0.0000	0.0000

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
2	0.9778	0.0000	0.0000	0.0000	0.9754	-2.0878	0.0000	0.0000	0.9750	2.0928	0.0000	0.0000
3	0.9782	0.0005	0.0012	0.0007	0.9759	-2.0874	0.0013	0.0009	0.9754	2.0931	0.0015	0.0009
4	0.9784	0.0011	0.0016	0.0012	0.9761	-2.0870	0.0019	0.0014	0.9756	2.0935	0.0022	0.0011
5	0.9747	0.0002	0.0013	0.0009	0.9721	-2.0877	0.0012	0.0008	0.9711	2.0919	0.0016	0.0009
6	0.9658	-0.0062	0.0013	0.0005	0.9640	-2.0912	0.0015	0.0009	0.9648	2.0894	0.0012	0.0007
7	0.9652	-0.0085	0.0000	0.0000	0.9642	-2.0927	0.0000	0.0000	0.9642	2.0878	0.0000	0.0000
8	0.9577	-0.0096	0.0011	0.0003	0.9562	-2.0927	0.0014	0.0009	0.9577	2.0878	0.0012	0.0008
9	0.9772	-0.0064	0.0020	0.0013	0.9770	-2.0930	0.0017	0.0012	0.9771	2.0890	0.0017	0.0010
10	0.9945	-0.0041	0.0012	0.0008	0.9941	-2.0934	0.0013	0.0010	0.9937	2.0906	0.0015	0.0010
11	1.0147	-0.0019	0.0015	0.0009	1.0147	-2.0940	0.0012	0.0007	1.0140	2.0923	0.0014	0.0009
12	1.0195	0.0082	0.0017	0.0013	1.0190	-2.0849	0.0020	0.0016	1.0176	2.1015	0.0024	0.0014
13	1.0339	-0.0092	0.0012	0.0009	1.0339	-2.1036	0.0016	0.0012	1.0339	2.0852	0.0014	0.0011
14	0.9556	-0.0115	0.0016	0.0006	0.9544	-2.0938	0.0019	0.0007	0.9545	2.0862	0.0022	0.0010
15	0.9518	-0.0123	0.0041	0.0014	0.9522	-2.0943	0.0031	0.0010	0.9535	2.0867	0.0023	0.0011
16	0.9621	-0.0098	0.0015	0.0004	0.9614	-2.0929	0.0012	0.0005	0.9605	2.0867	0.0017	0.0007
17	0.9532	-0.0127	0.0012	0.0003	0.9515	-2.0935	0.0011	0.0007	0.9507	2.0855	0.0015	0.0009

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
18	0.9861	-0.0015	0.0012	0.0008	0.9840	-2.0908	0.0013	0.0009	0.9826	2.0915	0.0015	0.0010
19	1.0472	-0.0084	0.0021	0.0018	1.0472	-2.1028	0.0017	0.0014	1.0472	2.0860	0.0017	0.0016
20	1.0050	-0.0036	0.0013	0.0010	1.0039	-2.0953	0.0012	0.0008	1.0013	2.0907	0.0015	0.0011
21	0.9781	-0.0012	0.0017	0.0010	0.9760	-2.0895	0.0013	0.0010	0.9746	2.0911	0.0015	0.0010
22	0.9744	-0.0005	0.0016	0.0011	0.9713	-2.0885	0.0019	0.0013	0.9703	2.0909	0.0023	0.0012
23	0.9936	0.0098	0.0020	0.0015	0.9922	-2.0801	0.0016	0.0013	0.9915	2.1019	0.0023	0.0011
24	1.0140	0.0181	0.0012	0.0009	1.0129	-2.0739	0.0014	0.0010	1.0125	2.1111	0.0017	0.0011
25	1.0374	0.0260	0.0021	0.0017	1.0374	-2.0684	0.0018	0.0011	1.0374	2.1204	0.0014	0.0013
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0213	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	0.9999	0.0061	0.9507	1.0472

TABLE XXXII. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG19=15 AND F025=1.003

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0067	0.0070	0.0072	0.0094	0.0102	0.0107
19	0.0106	0.0100	0.0109	0.0091	0.0093	0.0094
25	0.0204	0.0198	0.0217	0.0041	0.0041	0.0046

TABLE XXXIII. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG19=17 AND F025=1.003

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9776	0.0000	0.0000	0.0000	0.9754	-2.0878	0.0000	0.0000	0.9748	2.0926	0.0000	0.0000
2	0.9776	0.0000	0.0000	0.0000	0.9754	-2.0878	0.0000	0.0000	0.9748	2.0926	0.0000	0.0000
3	0.9781	0.0006	0.0012	0.0007	0.9758	-2.0874	0.0013	0.0009	0.9752	2.0930	0.0015	0.0009
4	0.9783	0.0010	0.0016	0.0012	0.9761	-2.0871	0.0019	0.0014	0.9754	2.0933	0.0022	0.0011
5	0.9746	0.0008	0.0013	0.0009	0.9721	-2.0871	0.0012	0.0008	0.9709	2.0923	0.0016	0.0009
6	0.9657	-0.0074	0.0013	0.0005	0.9639	-2.0924	0.0015	0.0009	0.9646	2.0880	0.0012	0.0007
7	0.9650	-0.0106	0.0000	0.0000	0.9641	-2.0949	0.0000	0.0000	0.9640	2.0855	0.0000	0.0000
8	0.9575	-0.0111	0.0011	0.0003	0.9561	-2.0942	0.0014	0.0009	0.9575	2.0862	0.0012	0.0008
9	0.9770	-0.0098	0.0020	0.0013	0.9768	-2.0964	0.0017	0.0012	0.9768	2.0855	0.0017	0.0010
10	0.9942	-0.0086	0.0012	0.0008	0.9938	-2.0979	0.0013	0.0010	0.9935	2.0860	0.0015	0.0010
11	1.0144	-0.0075	0.0015	0.0009	1.0144	-2.0997	0.0012	0.0007	1.0137	2.0867	0.0014	0.0009
12	1.0191	0.0026	0.0017	0.0013	1.0187	-2.0905	0.0020	0.0016	1.0173	2.0959	0.0024	0.0014
13	**1.0337**	**-0.0159**	**0.0012**	**0.0009**	**1.0337**	**-2.1103**	**0.0016**	**0.0012**	**1.0337**	**2.0785**	**0.0014**	**0.0011**
14	0.9554	-0.0134	0.0016	0.0006	0.9543	-2.0958	0.0019	0.0007	0.9543	2.0841	0.0022	0.0010

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
15	0.9517	-0.0140	0.0041	0.0014	0.9521	-2.0961	0.0031	0.0010	0.9533	2.0849	0.0023	0.0011
16	0.9620	-0.0120	0.0015	0.0004	0.9613	-2.0951	0.0012	0.0005	0.9603	2.0844	0.0017	0.0007
17	0.9530	-0.0146	0.0012	0.0003	0.9514	-2.0955	0.0011	0.0007	0.9505	2.0834	0.0015	0.0009
18	0.9861	0.0011	0.0012	0.0008	0.9842	-2.0883	0.0013	0.0009	0.9824	2.0938	0.0015	0.0010
19	**1.0476**	**0.0026**	**0.0021**	**0.0018**	**1.0476**	**-2.0918**	**0.0017**	**0.0014**	**1.0476**	**2.0970**	**0.0017**	**0.0016**
20	1.0050	0.0020	0.0013	0.0010	1.0041	-2.0898	0.0012	0.0008	1.0012	2.0959	0.0015	0.0011
21	0.9781	0.0007	0.0017	0.0010	0.9760	-2.0876	0.0013	0.0010	0.9745	2.0928	0.0015	0.0010
22	0.9743	0.0007	0.0016	0.0011	0.9714	-2.0873	0.0019	0.0013	0.9702	2.0919	0.0023	0.0012
23	0.9934	0.0078	0.0020	0.0015	0.9921	-2.0821	0.0016	0.0013	0.9913	2.0998	0.0023	0.0011
24	1.0137	0.0143	0.0012	0.0009	1.0127	-2.0778	0.0014	0.0010	1.0121	2.1072	0.0017	0.0011
25	**1.0370**	**0.0204**	**0.0021**	**0.0017**	**1.0370**	**-2.0740**	**0.0018**	**0.0011**	**1.0370**	**2.1148**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0212	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	1.0000	0.0060	0.9505	1.0476

TABLE XXXIV. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG19=17 AND F025=1.003

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0064	0.0067	0.0069	0.0099	0.0106	0.0112
19	0.0114	0.0108	0.0118	0.0080	0.0082	0.0082
25	0.0198	0.0192	0.0211	0.0048	0.0048	0.0052

TABLE XXXV. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG19=15 AND F025=1.0031

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9778	0.0000	0.0000	0.0000	0.9754	-2.0878	0.0000	0.0000	0.9751	2.0928	0.0000	0.0000
2	0.9778	0.0000	0.0000	0.0000	0.9754	-2.0878	0.0000	0.0000	0.9751	2.0928	0.0000	0.0000
3	0.9783	0.0005	0.0012	0.0007	0.9759	-2.0874	0.0013	0.0009	0.9755	2.0932	0.0015	0.0009
4	0.9785	0.0011	0.0016	0.0012	0.9761	-2.0870	0.0019	0.0014	0.9757	2.0936	0.0022	0.0011
5	0.9747	0.0001	0.0013	0.0009	0.9721	-2.0878	0.0012	0.0008	0.9711	2.0918	0.0016	0.0009
6	0.9659	-0.0061	0.0013	0.0005	0.9640	-2.0910	0.0015	0.0009	0.9648	2.0895	0.0012	0.0007
7	0.9652	-0.0083	0.0000	0.0000	0.9642	-2.0925	0.0000	0.0000	0.9643	2.0880	0.0000	0.0000
8	0.9577	-0.0095	0.0011	0.0003	0.9562	-2.0926	0.0014	0.0009	0.9577	2.0880	0.0012	0.0008

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
9	0.9772	-0.0061	0.0020	0.0013	0.9770	-2.0927	0.0017	0.0012	0.9771	2.0893	0.0017	0.0010
10	0.9945	-0.0037	0.0012	0.0008	0.9941	-2.0930	0.0013	0.0010	0.9937	2.0910	0.0015	0.0010
11	1.0147	-0.0014	0.0015	0.0009	1.0147	-2.0935	0.0012	0.0007	1.0140	2.0928	0.0014	0.0009
12	1.0195	0.0092	0.0017	0.0013	1.0191	-2.0839	0.0020	0.0016	1.0176	2.1025	0.0024	0.0014
13	1.0339	-0.0091	0.0012	0.0009	1.0339	-2.1035	0.0016	0.0012	1.0339	2.0853	0.0014	**0.0011**
14	0.9556	-0.0113	0.0016	0.0006	0.9545	-2.0936	0.0019	0.0007	0.9545	2.0864	0.0022	0.0010
15	0.9519	-0.0121	0.0041	0.0014	0.9522	-2.0942	0.0031	0.0010	0.9535	2.0869	0.0023	0.0011
16	0.9622	-0.0096	0.0015	0.0004	0.9614	-2.0927	0.0012	0.0005	0.9606	2.0869	0.0017	0.0007
17	0.9532	-0.0125	0.0012	0.0003	0.9515	-2.0933	0.0011	0.0007	0.9507	2.0857	0.0015	0.0009
18	0.9862	-0.0021	0.0012	0.0008	0.9840	-2.0914	0.0013	0.0009	0.9827	2.0909	0.0015	0.0010
19	1.0471	-0.0111	0.0021	0.0018	1.0471	-2.1055	0.0017	0.0014	1.0471	2.0833	0.0017	**0.0016**
20	1.0050	-0.0049	0.0013	0.0010	1.0038	-2.0967	0.0012	0.0008	1.0013	2.0894	0.0015	0.0011
21	0.9782	-0.0017	0.0017	0.0010	0.9760	-2.0900	0.0013	0.0010	0.9747	2.0907	0.0015	0.0010
22	0.9744	-0.0008	0.0016	0.0011	0.9713	-2.0888	0.0019	0.0013	0.9704	2.0907	0.0023	0.0012
23	0.9937	0.0104	0.0020	0.0015	0.9923	-2.0795	0.0016	0.0013	0.9916	2.1026	0.0023	0.0011
24	1.0141	0.0194	0.0012	0.0009	1.0131	-2.0727	0.0014	0.0010	1.0126	2.1124	0.0017	0.0011

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
25	1.0377	0.0279	0.0021	0.0017	1.0377	-2.0665	0.0018	0.0011	1.0377	2.1223	0.0014	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0213	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	0.9999	0.0062	0.9507	1.0471

TABLE XXXVI. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG19=15 AND F025=1.0031

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0066	0.0068	0.0071	0.0096	0.0103	0.0108
19	0.0103	0.0098	0.0106	0.0094	0.0096	0.0097
25	0.0208	0.0201	0.0221	0.0038	0.0037	0.0042

TABLE XXXVII. VOLTAGE PROFILE AND LOADS RESULTS OF THE PROPOSED POWER FLOW IN 25-BUS UNBALANCED TEST SYSTEM, KG19=15 AND F025=1.0032

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
1	0.9778	0.0000	0.0000	0.0000	0.9754	-2.0878	0.0000	0.0000	0.9751	2.0929	0.0000	0.0000

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
2	0.9778	0.0000	0.0000	0.0000	0.9754	-2.0878	0.0000	0.0000	0.9751	2.0929	0.0000	0.0000
3	0.9783	0.0005	0.0012	0.0007	0.9759	-2.0874	0.0013	0.0009	0.9756	2.0932	0.0015	0.0009
4	0.9785	0.0011	0.0016	0.0012	0.9761	-2.0870	0.0019	0.0014	0.9757	2.0936	0.0022	0.0011
5	0.9748	-0.0001	0.0013	0.0009	0.9721	-2.0879	0.0012	0.0008	0.9712	2.0917	0.0016	0.0009
6	0.9659	-0.0060	0.0013	0.0005	0.9640	-2.0909	0.0015	0.0009	0.9649	2.0896	0.0012	0.0007
7	0.9652	-0.0081	0.0000	0.0000	0.9642	-2.0923	0.0000	0.0000	0.9643	2.0883	0.0000	0.0000
8	0.9578	-0.0094	0.0011	0.0003	0.9562	-2.0924	0.0014	0.0009	0.9578	2.0881	0.0012	0.0008
9	0.9772	-0.0058	0.0020	0.0013	0.9770	-2.0924	0.0017	0.0012	0.9771	2.0896	0.0017	0.0010
10	0.9945	-0.0033	0.0012	0.0008	0.9941	-2.0926	0.0013	0.0010	0.9937	2.0914	0.0015	0.0010
11	1.0147	-0.0009	0.0015	0.0009	1.0147	-2.0930	0.0012	0.0007	1.0139	2.0933	0.0014	0.0009
12	1.0196	0.0102	0.0017	0.0013	1.0191	-2.0829	0.0020	0.0016	1.0177	2.1034	0.0024	0.0014
13	**1.0338**	**-0.0090**	**0.0012**	**0.0009**	**1.0338**	**-2.1034**	**0.0016**	**0.0012**	**1.0338**	**2.0854**	**0.0014**	**0.0011**
14	0.9556	-0.0111	0.0016	0.0006	0.9545	-2.0935	0.0019	0.0007	0.9546	2.0866	0.0022	0.0010
15	0.9519	-0.0120	0.0041	0.0014	0.9522	-2.0940	0.0031	0.0010	0.9536	2.0870	0.0023	0.0011
16	0.9622	-0.0094	0.0015	0.0004	0.9614	-2.0925	0.0012	0.0005	0.9606	2.0871	0.0017	0.0007
17	0.9532	-0.0123	0.0012	0.0003	0.9515	-2.0932	0.0011	0.0007	0.9507	2.0859	0.0015	0.0009

Bus n0	Phase A				Phase B				Phase C			
	Van (pu,rad)		Load (pu)		Vbn (pu,rad)		Load (pu)		Vcn (pu,rad)		Load (pu)	
	Mag	Agl	P	Q	Mag	Agl	P	Q	Mag	Agl	P	Q
18	0.9862	-0.0027	0.0012	0.0008	0.9840	-2.0919	0.0013	0.0009	0.9827	2.0904	0.0015	0.0010
19	**1.0471**	**-0.0137**	**0.0021**	**0.0018**	**1.0471**	**-2.1081**	**0.0017**	**0.0014**	**1.0471**	**2.0807**	**0.0017**	**0.0016**
20	1.0050	-0.0063	0.0013	0.0010	1.0038	-2.0980	0.0012	0.0008	1.0014	2.0882	0.0015	0.0011
21	0.9782	-0.0021	0.0017	0.0010	0.9759	-2.0904	0.0013	0.0010	0.9747	2.0903	0.0015	0.0010
22	0.9744	-0.0011	0.0016	0.0011	0.9713	-2.0891	0.0019	0.0013	0.9704	2.0904	0.0023	0.0012
23	0.9937	0.0111	0.0020	0.0015	0.9924	-2.0788	0.0016	0.0013	0.9917	2.1033	0.0023	0.0011
24	1.0143	0.0207	0.0012	0.0009	1.0132	-2.0714	0.0014	0.0010	1.0128	2.1137	0.0017	0.0011
25	**1.0379**	**0.0297**	**0.0021**	**0.0017**	**1.0379**	**-2.0647**	**0.0018**	**0.0011**	**1.0379**	**2.1241**	**0.0014**	**0.0013**
Total	**PLa**	**QLa**	**PLb**	**QLb**	**PLc**	**QLc**	**PLtotal**	**QLtotal**	**f/pu**	**Ploss**	**Vmin/pu**	**Vmax/pu**
	0.0357	0.0213	0.0347	0.0223	0.0377	0.0377	0.1081	0.0813	1.0000	0.0063	0.9507	1.0471

TABLE XXXVIII. DG UNITS REAL AND REACTIVE POWER GENERATION IN 25-BUS UNBALANCED TEST SYSTEM, KG19=15 AND F025=1.0032

Busid(DG)	PGa	PGb	PGc	QGa	QGb	QGc
13	0.0065	0.0067	0.0069	0.0097	0.0105	0.0110
19	0.0101	0.0096	0.0104	0.0096	0.0099	0.0100
25	0.0211	0.0205	0.0226	0.0034	0.0033	0.0038

II. CHAPTER 3

II.1. 38_bus test system

TABLE I. GENERAL RESULT OF OPTIMAL LOAD FLOW ON 38_BUS SYSTEM

N0. Iteration	Load flow, pu				optimization, pu	
	Number	PGi	KG	Ploss (calculated by B coefficients)	PGinew	Kgnew
1	1(Droop)	1.1431	394.0497	0.0546	0.7434	256.2716
	2(Droop)	0.6790	234.0497		0.8158	281.2228
	3(Droop)	0.6210	214.0497		0.7276	250.8125
	4(Droop)	0.5629	194.0497		0.6653	229.3306
	5(Droop)	0.6790	234.0497		0.7285	251.1261
2	1(Droop)	0.7437	**256.2716**	**0.0478**		
	2(Droop)	0.8161	**281.2228**			
	3(Droop)	0.7279	**250.8125**			
	4(Droop)	0.6655	**229.3306**			
	5(Droop)	0.7288	**251.1261**			

TABLE II. LOAD FLOW RESULT OF ITERATION 1 (INITIAL OPERATING POINT), PU

Bus	Vi	di	PGi	Qgi	PLi	QLi
1	1.0062	0.0000	1.1431	0.2276	0.0000	0.0000
2	0.9931	-0.0082	0.6790	0.5079	0.0000	0.0000
3	0.9959	-0.0146	0.6210	0.4238	0.0000	0.0000
4	0.9952	-0.0157	0.5629	0.2955	0.0000	0.0000
5	0.9913	-0.0259	0.6790	0.7461	0.0000	0.0000
6	0.9827	-0.0197	0.0000	0.0000	0.0000	0.0000

Bus	Vi	di	PGi	Qgi	PLi	QLi
7	0.9850	-0.0117	0.0000	0.0000	0.1949	0.0953
8	0.9893	-0.0115	0.0000	0.0000	0.1962	0.0967
9	0.9896	-0.0125	0.0000	0.0000	0.0597	0.0188
10	0.9903	-0.0134	0.0000	0.0000	0.0590	0.0194
11	0.9904	-0.0136	0.0000	0.0000	0.0442	0.0291
12	0.9909	-0.0139	0.0000	0.0000	0.0593	0.0338
13	0.9903	-0.0160	0.0000	0.0000	0.0590	0.0340
14	0.9883	-0.0172	0.0000	0.0000	0.1184	0.0765
15	0.9870	-0.0178	0.0000	0.0000	0.0587	0.0096
16	0.9858	-0.0182	0.0000	0.0000	0.0597	0.0184
17	0.9840	-0.0194	0.0000	0.0000	0.0584	0.0190
18	0.9835	-0.0195	0.0000	0.0000	0.0895	0.0363
19	0.9830	-0.0196	0.0000	0.0000	0.0883	0.0374
20	0.9873	-0.0188	0.0000	0.0000	0.0880	0.0384
21	0.9889	-0.0182	0.0000	0.0000	0.0896	0.0375
22	0.9925	-0.0165	0.0000	0.0000	0.0891	0.0389
23	0.9821	-0.0210	0.0000	0.0000	0.0873	0.0472
24	0.9829	-0.0237	0.0000	0.0000	0.4080	0.1892
25	0.9869	-0.0257	0.0000	0.0000	0.4105	0.1918
26	0.9831	-0.0139	0.0000	0.0000	0.0583	0.0237
27	0.9825	-0.0134	0.0000	0.0000	0.0596	0.0226
28	0.9798	-0.0118	0.0000	0.0000	0.0580	0.0187
29	0.9782	-0.0104	0.0000	0.0000	0.1157	0.0651

Bus	Vi	di	PGi	Qgi	PLi	QLi
30	0.9750	-0.0090	0.0000	0.0000	0.1919	0.5522
31	0.9713	-0.0103	0.0000	0.0000	0.1456	0.0624
32	0.9705	-0.0107	0.0000	0.0000	0.2037	0.0889
33	0.9703	-0.0108	0.0000	0.0000	0.0572	0.0362
34	0.9837	-0.0142	0.0000	0.0000	0.0596	0.0182
35	0.9827	-0.0197	0.0000	0.0000	0.0981	0.0561
36	0.9822	-0.0196	0.0000	0.0000	0.0894	0.0360
37	0.9823	-0.0185	0.0000	0.0000	0.1165	0.0755
38	0.9827	-0.0174	0.0000	0.0000	0.0589	0.0280
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	3.6850	2.2008	3.6304	2.1508	0.9971	0.0546

TABLE III. LOAD FLOW RESULT OF ITERATION 2 (OPTIMAL OPERATING POINT), PU

Bus	Vi	di	PGi	Qgi	PLi	QLi
1	1.0030	0.0000	0.7437	0.4201	0.0000	0.0000
2	0.9952	0.0068	0.8161	0.4453	0.0000	0.0000
3	0.9972	-0.0035	0.7279	0.3830	0.0000	0.0000
4	0.9974	-0.0004	0.6655	0.2515	0.0000	0.0000
5	0.9924	-0.0126	0.7288	0.7028	0.0000	0.0000
6	0.9838	-0.0075	0.0000	0.0000	0.0000	0.0000
7	0.9853	-0.0032	0.0000	0.0000	0.1950	0.0954
8	0.9886	-0.0041	0.0000	0.0000	0.1960	0.0964
9	0.9893	-0.0043	0.0000	0.0000	0.0597	0.0188
10	0.9905	-0.0045	0.0000	0.0000	0.0590	0.0194

Bus	Vi	di	PGi	Qgi	PLi	QLi
11	0.9908	-0.0045	0.0000	0.0000	0.0442	0.0292
12	0.9914	-0.0047	0.0000	0.0000	0.0594	0.0339
13	0.9917	-0.0049	0.0000	0.0000	0.0591	0.0341
14	0.9897	-0.0061	0.0000	0.0000	0.1185	0.0769
15	0.9884	-0.0067	0.0000	0.0000	0.0588	0.0096
16	0.9872	-0.0071	0.0000	0.0000	0.0597	0.0186
17	0.9853	-0.0082	0.0000	0.0000	0.0585	0.0191
18	0.9848	-0.0084	0.0000	0.0000	0.0895	0.0366
19	0.9842	-0.0073	0.0000	0.0000	0.0884	0.0376
20	0.9890	-0.0052	0.0000	0.0000	0.0883	0.0386
21	0.9908	-0.0041	0.0000	0.0000	0.0896	0.0379
22	0.9946	-0.0017	0.0000	0.0000	0.0893	0.0392
23	0.9831	-0.0089	0.0000	0.0000	0.0875	0.0473
24	0.9839	-0.0112	0.0000	0.0000	0.4087	0.1898
25	0.9879	-0.0127	0.0000	0.0000	0.4112	0.1925
26	0.9832	-0.0039	0.0000	0.0000	0.0583	0.0237
27	0.9828	-0.0031	0.0000	0.0000	0.0596	0.0226
28	0.9806	-0.0002	0.0000	0.0000	0.0581	0.0188
29	0.9794	0.0021	0.0000	0.0000	0.1159	0.0654
30	0.9762	0.0036	0.0000	0.0000	0.1923	0.5544
31	0.9725	0.0022	0.0000	0.0000	0.1458	0.0627
32	0.9717	0.0018	0.0000	0.0000	0.2039	0.0893
33	0.9714	0.0017	0.0000	0.0000	0.0573	0.0364

Bus	Vi	di	PGi	Qgi	PLi	QLi
34	0.9837	-0.0044	0.0000	0.0000	0.0596	0.0182
35	0.9838	-0.0075	0.0000	0.0000	0.0982	0.0563
36	0.9831	-0.0078	0.0000	0.0000	0.0895	0.0362
37	0.9829	-0.0070	0.0000	0.0000	0.1166	0.0757
38	0.9831	-0.0063	0.0000	0.0000	0.0589	0.0281
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	3.6820	2.2027	3.6343	2.1588	0.9971	0.0478

II.2. 6_bus test system

TABLE IV. GENERAL RESULT OF OPTIMAL LOAD FLOW ON 6_BUS SYSTEM

N0. Iteration	Load flow, pu				Optimization, pu	
	Number	P_{Gi}	K_G	Ploss (calculated by B coefficients)	P_{Ginew}	K_{Gnew}
1	1(Droop)	0.3916	401.0638	0.0265391	0.3978	407.375
	2(Droop)	0.3916	401.0638		0.3016	308.8672
	3(Droop)	0.3916	401.0638		0.4747	486.2074
2	1(Droop)	0.3978	407.3750	0.0241074	0.3968	406.3396
	2(Droop)	0.3016	308.8672		0.2165	221.7403
	3(Droop)	0.4748	486.2074		0.5599	573.4366
3	1(Droop)	0.3972	**406.3396**	**0.0228142**		
	2(Droop)	0.2167	**221.7403**			
	3(Droop)	0.5605	**573.4366**			

TABLE V. LOAD FLOW RESULT OF ITERATION 1 (INITIAL OPERATING POINT), PU

Bus	Vi	di	PGi	Qgi	PLi	Qli
1	0.9892	0.0000	0.3916	0.1904	0.0000	0.0000
2	0.9920	-0.0066	0.3916	0.1416	0.0000	0.0000
3	0.9730	-0.0497	0.3916	0.4781	0.0000	0.0000
4	0.9620	0.0011	0.0000	0.0000	0.4899	0.3242
5	0.9745	-0.0083	0.0000	0.0000	0.0000	0.0000
6	0.9674	-0.0464	0.0000	0.0000	0.6585	0.4654
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	1.1748	0.8101	1.1484	0.7896	0.9990	0.0264

TABLE VI. LOAD FLOW RESULT OF ITERATION 2, PU

Bus	Vi	di	PGi	Qgi	PLi	Qli
1	0.9901	0.0000	0.3978	0.1745	0.0000	0.0000
2	0.9901	-0.0122	0.3016	0.1750	0.0000	0.0000
3	0.9742	-0.0396	0.4748	0.4557	0.0000	0.0000
4	0.9630	0.0000	0.0000	0.0000	0.4908	0.3248
5	0.9754	-0.0109	0.0000	0.0000	0.0000	0.0000
6	0.9680	-0.0368	0.0000	0.0000	0.6592	0.4659
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	1.1741	0.8053	1.1501	0.7908	0.9990	0.0241

TABLE VII. LOAD FLOW RESULT OF ITERATION 3 (OPTIMAL OPERATING POINT), PU

Bus	Vi	di	PGi	Qgi	PLi	Qli
1	0.9906	0.0000	0.3972	0.1659	0.0000	0.0000

Bus	Vi	di	PGi	Qgi	PLi	Qli
2	0.9885	-0.0162	0.2167	0.2040	0.0000	0.0000
3	0.9755	-0.0278	0.5605	0.4327	0.0000	0.0000
4	0.9637	-0.0005	0.0000	0.0000	0.4916	0.3253
5	0.9765	-0.0122	0.0000	0.0000	0.0000	0.0000
6	0.9685	-0.0256	0.0000	0.0000	0.6600	0.4665
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	1.1744	0.8026	1.1516	0.7918	0.9990	0.0228

III. CHAPTER 4

III.1. Accuracy of results

III.1.1. Electrical data of 6_bus test system

TABLE I. BUS DATAS OF 6_BUS TEST SYSTEM, TAKING INTO ACCOUNT KGS

Bus number	**Load, pu**		**Generator, pu**			**Exponent of Loads**	
	P	**Q**	**Kdi**	**VG0i**	**f0i/pu**	**Alpha**	**Beta**
1	0.000000000	0.000000000	5.00	1.07	1.07	0.00	0.00
2	0.000000000	0.000000000	5.00	1.07	1.07	0.00	0.00
3	0.000000000	0.000000000	5.00	1.07	1.07	0.00	0.00
4	0.529334489	0.350297754		0.00	1.00	2.00	2.00
5	0.000000000	0.000000000		0.00	1.00	2.00	2.00
6	0.351794954	0.248636718		0.00	1.00	2.00	2.00

TABLE II. LINES DATAS OF 6_BUS TEST SYSTEM, TAKING INTO ACCOUNT KGS

Bus nl	**Bus nr**	**R, pu**	**X, pu**
4	5	0.08128544	0.02266228
4	1	0.05671078	0.02494276
5	2	0.03780718	0.01781626
5	6	0.02835539	0.13134145
6	3	0.00945180	0.00356325

TABLE III. LIMIT OF KGS ON 6_BUS BALANCED TEST SYSTEM, TAKING INTO ACCOUNT KGS

Generators	Kgmin,pu	Kgmax,pu
G1	1	25
G2	1	25
G3	1	25

III.1.2. Lagrange method

TABLE IV. GENERAL RESULT OF OPTIMAL LOAD FLOW ON 6_BUS SYSTEM

N0. Iteration	Load flow, pu				optimization, pu	
	Number	PGi	KG	Ploss (calculated by B coefficients)	PGinew	Kgnew
1	1(Droop)	0.3056	17.4655	0.0192058	0.347	19.8331
	2(Droop)	0.3056	17.4655		0.1816	10.3798
	3(Droop)	0.3056	17.4655		0.3868	22.1034
2	1(Droop)	0.3479	**19.8331**	**0.0178887**		
	2(Droop)	0.1821	**10.3798**			
	3(Droop)	0.3878	**22.1034**			

TABLE V. LOAD FLOW RESULT OF ITERATION 1 (INITIAL OPERATING POINT), PU

Bus	Vi	di	PGi	Qgi	PLi	Qli
1	1.0249	0.0000	0.3056	0.2256	0.0000	0.0000
2	1.0383	-0.0006	0.3056	0.1586	0.0000	0.0000
3	1.0231	-0.0082	0.3056	0.2343	0.0000	0.0000
4	1.0025	0.0050	0.0000	0.0000	0.5320	0.3520
5	1.0244	-0.0001	0.0000	0.0000	0.0000	0.0000

Bus	Vi	di	PGi	Qgi	PLi	Qli
6	1.0195	-0.0071	0.0000	0.0000	0.3657	0.2584
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.9168	0.6185	0.8976	0.6105	1.0525	0.0192058

TABLE VI. LOAD FLOW RESULT OF ITERATION 2 (OPTIMAL OPERATING POINT), PU

Bus	Vi	di	PGi	Qgi	PLi	Qli
1	1.0285	0.0000	0.3479	0.2075	0.0000	0.0000
2	1.0333	-0.0081	0.1821	0.1836	0.0000	0.0000
3	1.0244	-0.0019	0.3878	0.2282	0.0000	0.0000
4	1.0043	0.0030	0.0000	0.0000	0.5339	0.3533
5	1.0235	-0.0046	0.0000	0.0000	0.0000	0.0000
6	1.0200	-0.0012	0.0000	0.0000	0.3660	0.2587
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.9178	0.6192	0.8999	0.6120	1.0525	0.0178887

III.1.3. GSO method

TABLE VII. OPTIMAL LOAD FLOW RESULT OF RANDOM 1, PU

Bus	Vi	di	PGi	Qgi	PLi	Qli
1	1.0283	0.0000	0.3440	0.2087	0.0000	0.0000
2	1.0329	-0.0081	0.1643	0.1856	0.0000	0.0000
3	1.0249	0.0013	0.4097	0.2253	0.0000	0.0000
4	1.0042	0.0032	0.0000	0.0000	0.5624	0.3343
5	1.0237	-0.0042	0.0000	0.0000	0.0000	0.0000

Bus	Vi	di	PGi	Qgi	PLi	Qli
6	1.0204	0.0019	0.0000	0.0000	0.3859	0.2450
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.9180	0.6195	0.9001	0.6122	1.0536	0.0178565

TABLE VIII. OPTIMAL LOAD FLOW RESULT OF RANDOM 2, PU

Bus	Vi	di	PGi	Qgi	PLi	QLi
1	1.0283	0.0000	0.3439	0.2087	0.0000	0.0000
2	1.0329	-0.0081	0.1638	0.1856	0.0000	0.0000
3	1.0250	0.0014	0.4103	0.2252	0.0000	0.0000
4	1.0042	0.0032	0.0000	0.0000	0.5338	0.3533
5	1.0237	-0.0042	0.0000	0.0000	0.0000	0.0000
6	1.0204	0.0020	0.0000	0.0000	0.3663	0.2589
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.9180	0.6195	0.9001	0.6122	1.0531	0.0178565

TABLE IX. OPTIMAL LOAD FLOW RESULT OF RANDOM 3, PU

Bus	Vi	di	PGi	Qgi	PLi	Qli
1	1.0283	0.0000	0.3439	0.2087	0.0000	0.0000
2	1.0329	-0.0081	0.1641	0.1856	0.0000	0.0000
3	1.0250	0.0013	0.4099	0.2252	0.0000	0.0000
4	1.0042	0.0032	0.0000	0.0000	0.5338	0.3533
5	1.0237	-0.0042	0.0000	0.0000	0.0000	0.0000
6	1.0204	0.0020	0.0000	0.0000	0.3663	0.2589

Bus	Vi	di	PGi	Qgi	PLi	Qli
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.9180	0.6195	0.9001	0.6122	1.0527	0.0178565

TABLE X. OPTIMAL LOAD FLOW RESULT OF RANDOM 4, PU

Bus	Vi	di	PGi	Qgi	PLi	Qli
1	1.0283	0.0000	0.3439	0.2087	0.0000	0.0000
2	1.0329	-0.0081	0.1639	0.1856	0.0000	0.0000
3	1.0250	0.0014	0.4102	0.2252	0.0000	0.0000
4	1.0042	0.0032	0.0000	0.0000	0.5338	0.3533
5	1.0237	-0.0042	0.0000	0.0000	0.0000	0.0000
6	1.0204	0.0020	0.0000	0.0000	0.3663	0.2589
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.9180	0.6195	0.9001	0.6122	1.0520	0.0178565

TABLE XI. OPTIMAL LOAD FLOW RESULT OF RANDOM 5, PU

Bus	Vi	di	PGi	Qgi	PLi	QLi
1	1.0283	0.0000	0.3439	0.2087	0.0000	0.0000
2	1.0329	-0.0081	0.1639	0.1856	0.0000	0.0000
3	1.0250	0.0014	0.4102	0.2252	0.0000	0.0000
4	1.0042	0.0032	0.0000	0.0000	0.5338	0.3533
5	1.0237	-0.0042	0.0000	0.0000	0.0000	0.0000
6	1.0204	0.0020	0.0000	0.0000	0.3663	0.2589
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.9180	0.6195	0.9001	0.6122	1.0535	0.0178565

III.2. Other applications with variable KGs and Kds

TABLE XII. BUS DATAS OF 6_ BUS TEST SYSTEM, TAKING INTO ACCOUNT KGS AND KDS

Bus number	Type generator	Load, pu		Generator, pu		Exponent of Loads	
		P	Q	VG0i	f0i/pu	Alpha	Beta
1	Droop	0.000000000	0.000000000	0.9877	1	0	0
2	Droop	0.000000000	0.000000000	0.9877	1	0	0
3	Droop	0.000000000	0.000000000	0.9877	1	0	0
4		0.052900000	0.000000000	0	1	2	2
5		0.052900000	0.000000000	0	1	2	2
6		0.027872043	0.026411745	0	1	2	2
7		0.000000000	0.000000000	0	1	2	2
8		0.000000000	0.000000000	0	1	2	2
9		0.000000000	0.000000000	0	1	2	2

TABLE XIII. LINES DATAS OF 6_BUS TEST SYSTEM, TAKING INTO ACCOUNT KGS AND KDS, PU

Bus nl	Bus nr	R, pu	X, pu
4	5	0.02835539	0.00441843
4	1	0.02835539	0.00441843
5	2	0.02835539	0.00441843
5	6	0.02835539	0.00441843
6	3	0.02835539	0.00441843
1	7	0.01890359	0.28506011
2	8	0.01890359	0.28506011
3	9	0.01890359	0.28506011

TABLE XIV. LIMIT OF KGS ON 6_BUS TEST SYSTEM TAKING INTO ACCOUNT KGS AND KDS, PU

Generators	**KGmin**	**KGmax**	**Kdmin**	**Kdmax**
G1	6	16	6	16
G2	3	10	3	10
G3	6	16	6	16

TABLE XV. OPTIMAL LOAD FLOW RESULT OF RANDOM 1, PU

Bus	**Vi**	**di**	**PGi**	**Qgi**	**PLi**	**Qli**
1	0.9869	0.0000	0.0491	0.0049	0.0000	0.0000
2	0.9868	0.0001	0.0456	0.0060	0.0000	0.0000
3	0.9868	0.0002	0.0353	0.0148	0.0000	0.0000
4	0.9854	-0.0001	0.0000	0.0000	0.0514	0.0000
5	0.9855	0.0001	0.0000	0.0000	0.0514	0.0000
6	0.9857	0.0004	0.0000	0.0000	0.0271	0.0257
7	0.9869	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.9868	0.0001	0.0000	0.0000	0.0000	0.0000
9	0.9868	0.0002	0.0000	0.0000	0.0000	0.0000
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.1300	0.0257	0.1298	0.0257	0.9949	0.00018143

TABLE XVI. OPTIMAL LOAD FLOW RESULT OF RANDOM 2, PU

Bus	**Vi**	**di**	**PGi**	**Qgi**	**PLi**	**Qli**
1	0.9869	0.0000	0.0493	0.0050	0.0000	0.0000
2	0.9868	0.0001	0.0453	0.0056	0.0000	0.0000
3	0.9868	0.0001	0.0355	0.0151	0.0000	0.0000

Bus	Vi	di	PGi	Qgi	PLi	Qli
4	0.9854	-0.0001	0.0000	0.0000	0.0514	0.0000
5	0.9855	0.0001	0.0000	0.0000	0.0514	0.0000
6	0.9857	0.0004	0.0000	0.0000	0.0271	0.0257
7	0.9869	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.9868	0.0001	0.0000	0.0000	0.0000	0.0000
9	0.9868	0.0001	0.0000	0.0000	0.0000	0.0000
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.1300	0.0257	0.1298	0.0257	0.9952	0.00018140

TABLE XVII. OPTIMAL LOAD FLOW RESULT OF RANDOM 3, PU

Bus	Vi	di	PGi	Qgi	PLi	QLi
1	0.9869	0.0000	0.0492	0.0050	0.0000	0.0000
2	0.9868	0.0001	0.0452	0.0057	0.0000	0.0000
3	0.9868	0.0002	0.0356	0.0150	0.0000	0.0000
4	0.9854	-0.0001	0.0000	0.0000	0.0514	0.0000
5	0.9855	0.0001	0.0000	0.0000	0.0514	0.0000
6	0.9857	0.0004	0.0000	0.0000	0.0271	0.0257
7	0.9869	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.9868	0.0001	0.0000	0.0000	0.0000	0.0000
9	0.9868	0.0002	0.0000	0.0000	0.0000	0.0000
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.1300	0.0257	0.1298	0.0257	0.9953	0.00018140

TABLE XVIII. OPTIMAL LOAD FLOW RESULT OF RANDOM 4, PU

Bus	Vi	di	PGi	Qgi	PLi	QLi
1	0.9869	0.0000	0.0492	0.0046	0.0000	0.0000
2	0.9869	0.0001	0.0457	0.0066	0.0000	0.0000
3	0.9868	0.0002	0.0351	0.0145	0.0000	0.0000
4	0.9855	-0.0001	0.0000	0.0000	0.0514	0.0000
5	0.9855	0.0001	0.0000	0.0000	0.0514	0.0000
6	0.9857	0.0004	0.0000	0.0000	0.0271	0.0257
7	0.9869	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.9869	0.0001	0.0000	0.0000	0.0000	0.0000
9	0.9868	0.0002	0.0000	0.0000	0.0000	0.0000
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	0.1300	0.0257	0.1298	0.0257	0.9952	0.00018147

TABLE XIX. OPTIMAL LOAD FLOW RESULT OF RANDOM 5, PU

Bus	Vi	di	PGi	Qgi	PLi	QLi
1	0.9869	0.0000	0.0492	0.0050	0.0000	0.0000
2	0.9868	0.0001	0.0451	0.0058	0.0000	0.0000
3	0.9868	0.0002	0.0358	0.0148	0.0000	0.0000
4	0.9854	-0.0001	0.0000	0.0000	0.0514	0.0000
5	0.9855	0.0001	0.0000	0.0000	0.0514	0.0000
6	0.9857	0.0004	0.0000	0.0000	0.0271	0.0257
7	0.9869	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.9868	0.0001	0.0000	0.0000	0.0000	0.0000
9	0.9868	0.0002	0.0000	0.0000	0.0000	0.0000

Total	PG	QG	PL	QL	f	Ploss
	0.1300	0.0257	0.1298	0.0257	0.9953	0.00018141

III.3. Applications considering frequency and line ampacity constraints

III.3.1. Application with variables KGs

TABLE XX. BUS DATAS OF 6_BUS TEST SYSTEM, TAKING INTO ACCOUNT CONSTRAINED FREQUENCY AND LINE AMPACITY WITH VARIABLES ARE KGS, PU

Bus number	Type generator	Load, pu		Generator, pu			Exponent of Loads	
		P	Q	Kdi	VG0i	f0i/pu	Alpha	Beta
1	Droop	0.0000	0.0000	5	1.07	1.03	0	0
2	Droop	0.0000	0.0000	5	1.07	1.03	0	0
3	Droop	0.0000	0.0000	5	1.07	1.03	0	0
4		0.5293	0.3532		0.00	1.00	2.00	2.00
5		0.2486	0.1486		0.00	1.00	2.00	2.00
6		0.3518	0.2486		0.00	1.00	2.00	2.00

TABLE XXI. LINES DATAS OF 6_BUS TEST SYSTEM, TAKING INTO ACCOUNT CONSTRAINED FREQUENCY AND LINE AMPACITY WITH VARIABLES ARE KGS

Bus nl	Bus nr	R, pu	X, pu
4	5	0.08128544	0.02266228
4	1	0.05671078	0.02494276
5	2	0.05671078	0.02494276
5	6	0.08128544	0.02266228
6	3	0.05671078	0.02494276

TABLE XXII. **OPTIMAL CURRENT LINE RESULT OF CASE 1, PU**

Bus nl	Bus nr	I opt case 1	DelI	Imax case 1
4	5	0.1254	0.2746	0.4000

Bus nl	Bus nr	I opt case 1	DelI	Imax case 1
4	1	0.4998	0.0002	0.5000
5	2	0.4103	0.0897	0.5000
5	6	0.0116	0.3884	0.4000
6	3	0.4247	0.0753	0.5000

TABLE XXIII. OPTIMAL LOAD FLOW RESULT OF CASE 1, PU

Bus	Vi	di	PGi	Qgi	PLi	QLi
1	1.0107	0.0000	0.3711	0.2965	0.0000	0.0000
2	1.0219	0.0018	0.3670	0.2403	0.0000	0.0000
3	1.0244	0.0060	0.3849	0.2280	0.0000	0.0000
4	0.9826	0.0076	0.0000	0.0000	0.5015	0.3473
5	0.9957	0.0062	0.0000	0.0000	0.2419	0.1501
6	0.9975	0.0093	0.0000	0.0000	0.3436	0.2520
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	1.1229	0.7648	1.0870	0.7494	0.9814	0.0359207

TABLE XXIV. OPTIMAL CURRENT LINE RESULT OF CASE 2, PU

Bus nl	Bus nr	I opt case 2	DelI	Imax case 2
4	5	0.1564	0.1436	0.3000
4	1	0.4700	0.0000	0.4700
5	2	0.4292	0.0708	0.5000
5	6	0.0420	0.2580	0.3000
6	3	0.4367	0.1633	0.6000

TABLE XXV. OPTIMAL LOAD FLOW RESULT OF CASE 2, PU

Bus	**Vi**	**di**	**PGi**	**Qgi**	**PLi**	**QLi**
1	1.0163	0.0000	0.4311	0.2686	0.0000	0.0000
2	1.0196	-0.0066	0.3340	0.2520	0.0000	0.0000
3	1.0209	-0.0047	0.3575	0.2453	0.0000	0.0000
4	0.9856	0.0045	0.0000	0.0000	0.5043	0.3497
5	0.9949	-0.0008	0.0000	0.0000	0.2413	0.1499
6	0.9951	0.0002	0.0000	0.0000	0.3417	0.2509
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	1.1225	0.7658	1.0873	0.7506	0.9808	0.0352283

III.3.2. Applications with variables KGs and Kds

TABLE XXVI. OPTIMAL CURRENT LINE RESULT OF CASE 1, PU

Bus nl	**Bus nr**	**I opt case 1**	**DelI**	**Imax case 1**
4	5	0.1280	0.2720	0.4000
4	1	0.4946	0.0054	0.5000
5	2	0.4143	0.0857	0.5000
5	6	0.0020	0.3980	0.4000
6	3	0.4247	0.0753	0.5000

TABLE XXVII. OPTIMAL LOAD FLOW RESULT OF CASE 1, PU

Bus	**Vi**	**di**	**PGi**	**Qgi**	**PLi**	**QLi**
1	1.0082	0.0000	0.4205	0.2680	0.0000	0.0000
2	1.0133	-0.0034	0.3529	0.2275	0.0000	0.0000
3	1.0137	-0.0042	0.3540	0.2452	0.0000	0.0000

Bus	Vi	di	PGi	Qgi	PLi	QLi
4	0.9779	0.0048	0.0000	0.0000	0.5024	0.3403
5	0.9879	0.0007	0.0000	0.0000	0.2408	0.1461
6	0.9879	0.0009	0.0000	0.0000	0.3408	0.2444
Total	**PG**	**QG**	**PL**	**QL**	**f**	**Ploss**
	1.1273	0.7407	1.0841	0.7308	0.9926	0.0351713