IET Generation, Transmission & Distribution

Research Article

Impact of reverse power flow on the optimal distributed generation placement problem

ISSN 1751-8687
Received on 11th November 2016
Revised 17th July 2017
Accepted on 22nd July 2017
E-First on 30th August 2017
doi: 10.1049/iet-gtd.2016.1791
www.ietdl.org

Kallisthenis I. Sgouras[1] ✉, Aggelos S. Bouhouras[1,2], Paschalis A. Gkaidatzis[1], Dimitrios I. Doukas[1], Dimitris P. Labridis[1]

[1]*School of Electrical and Computer Engineering, Aristotle University of Thessaloniki, 541 24 Thessaloniki, Greece*
[2]*Department of Electrical Engineering, Technological Educational Institute of Western Macedonia, 501 00 Kozani, Greece*
✉ *E-mail: ksgouras@ece.auth.gr*

Abstract: Integration of distributed generation (DG) in existing distribution networks has been studied thoroughly during the past years as a measure of reducing grid's power losses. However, the optimal DG placement, known as ODGP, toward loss minimisation, has not been studied in depth by considering the possible impact of the reverse power flow (RPF) caused by extended penetration of distributed energy resources. This study uses a constriction factor embedded local particle swarm optimisation algorithm along with the appropriate particle formulation that solves the ODGP problem by taking into account the impact of possible RPF. In this study, the idea of RPF modelling is introduced by providing extended versions of IEEE test systems. Modified versions of the IEEE 30-bus and IEEE 33-bus test systems are modelled and results are presented in order to highlight the impact of RPF on the ODGP problem solution. The mathematical formulation is given, results and analysis for both extended systems are presented, while the importance of RPF for different conditions is assessed.

1 Introduction

Over the past years, there have been made considerable efforts making use of different approaches to solve the problem of optimal sizing and allocation of distributed generators (DGs) [1–5] [known as optimal DG placement (ODGP) problem] in a distribution network (DN) such as analytical methods, numerical, and heuristics.

Analytical and numerical methods such as exhaustive analysis [6], improved analytical [7], utilisation of loss sensitivity factors [8], or other [9] provide an actual optimal solution but are confining the ODGP problem to one DG.

Efforts to solve the same problem have also been made by applying dynamic programming [10], heuristic methods or a blend of both analytical and heuristic methodologies. Evolutionary programming [11], genetic algorithm [12–14] are frequently used, while the more recent artificial bee colony [15] and honey bee mating optimisation [16] showing promising results in the field. Particle swarm optimisation (PSO) also has a considerable contribution in the field due to its ability to provide solutions efficiently, requiring minimal implementation effort [17–21]. According to the evaluation presented in [22], analytical methods provide indicative results due to the required simplifications, and numerical methods are not suitable for large-scale systems. For complex ODGP problems with multiple DGs, heuristic methods are considered robust and provide near-optimal solutions. Moreover, heuristic-based swarm intelligence consists of an efficient alternative to effectively solve large-scale non-linear (NL) optimisation problems, while analytical methods might suffer from slow convergence and the curse of dimensionality [23]. On the basis of the most recent literatures [22, 24], which point out heuristic methods as the most prevalent approaches to deal with the ODGP problem, working with such a method is necessary for a time-efficient but accurate solution to the problem.

Apart from the different approaches to solve the ODGP problem presented previously, recent increased integration of DG brought on the surface the need to consider the impact of reverse power flow (RPF) on the same problem [25–27]. On the one hand, solving the ODGP problem without considering the neighbouring conditions and adjacent grids can be proved inadequate by means that the problem of losses instead of being minimised can be just transferred to the adjacent(s) network(s). On the other hand, absolute prevention of RPF in advance may lead to a biased and less optimal solution of the ODGP problem. Thus, the RPF impact to the ODGP problem has to be studied thoroughly. In this paper, the constriction factor embedded local PSO (LPSO) variant is used in order to determine the optimal site and size of DGs in a DN. PSO has been chosen, since, based on literatures [23, 24], it consists a state-of-the-art heuristic technique applied to the ODGP problem, whereas is also able to effectively solve large-scale NL optimisation problems. Moreover, as pointed out in [28, 29], PSO techniques emerge as the most promising heuristic technique in terms of solution and convergence performance. It is important to mention that all variables involved in the solution process (location, number of units, and capacity) do not undergo any kind of limitations, and sizing in terms of both active and reactive powers is considered. The mathematical model proposed in [30] is used to formulate the objective function (OF), the constraints, and the penalty function. The procedure applied in [31] along with [32] are used to formulate the PSO algorithm.

Furthermore, the ODGP problem is solved by taking into account the impact of RPF on the solution. The modifications of the IEEE 30-bus and IEEE 33-bus systems to the extended ones have been done by assuming an impedance that represents the upstream conditions. Furthermore, the pre-existing slack bus (SB) on both systems has been modified to a typical PQ type bus with no load and an extra bus on the upstream area is the new SB. To cover a great variety of scenarios, five possible upstream impedances have been considered. Moreover, in order to model the RPF and its impact on the adjacent systems seven different RPF scenarios have been considered.

The contribution of this paper, especially as viewed by the aggregator's perspective, relies on appropriate RPF modelling in order to identify the influence of various RPF magnitudes on the siting and sizing of DG capacity toward loss minimisation.

This paper is organised as follows. In Section 2, the problem with RPF when examining ODGP is demonstrated. In Section 3, the idea of extended bus systems for the RPF implementation is analysed. In Section 4, the mathematical formulations of both the OF and the utilised PSO algorithm are presented. In Section 5, the

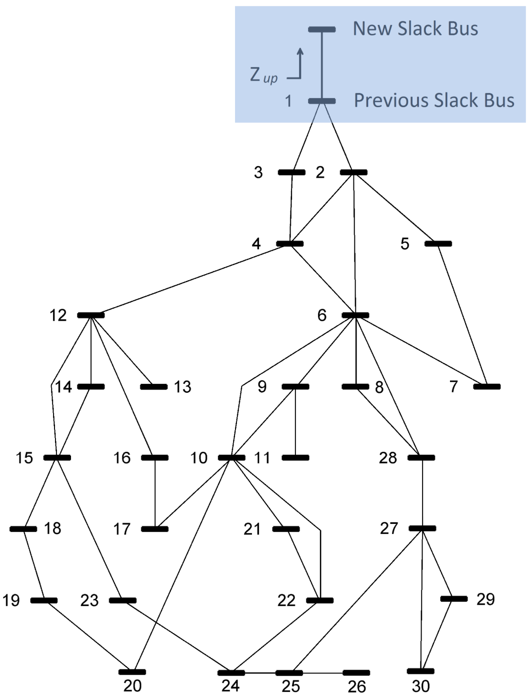

Fig. 1 *Extended IEEE 30-bus test system*

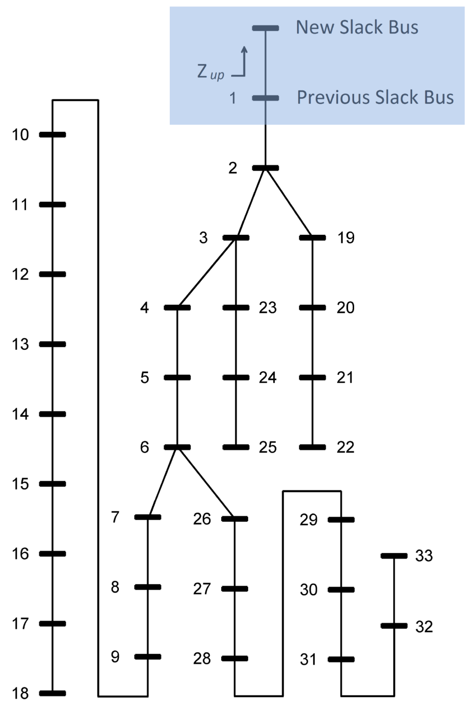

Fig. 2 *Extended IEEE 33-bus test system*

results of the proposed methodology are presented and discussed, and finally Section 6 is devoted to conclusions.

2 RPF within ODGP

Literature survey that has been conducted within this research brought to light that most researchers solve the ODGP problem without assessing the impact of RPF to the final solution. For example, the authors in [12, 33–35] provide solutions to the ODGP problem with improvements in loss reduction ranging from 7 to 30% without considering the RPF, as shown in Table 1.

In this table, in ascending order in terms of loss reduction, four studies are presented that solve the ODGP problem to the IEEE 30-bus test system. Although in study [34], a better loss reduction is achieved, when compared with study [33], increased amount of PFs through the SB to the DN from the rest of the network.

Table 1 ODGP without consideration of RPF

Study	Loss reduction, %	SB PF, MW
Singh and Goswami [35]	6.84	10.80
Wang and Nehrir [33]	9.57	20.00
Akorede *et al.* [34]	22.74	−49.58
Ghosh *et al.* [12]	30.66	-9.77

Table 2 Z_{up} in per unit values for all scenarios

Scenario number	Z_{up} multiplier	IEEE 30 bus	IEEE 33 bus
#1	0.05	0.00192	0.00108
#2	0.10	0.00384	0.00217
#3	0.25	0.00959	0.00541
#4	0.50	0.01919	0.01082
#5	1.00	0.03839	0.02164

Similarly, in study [12] a better solution is achieved compared with study [33], both in terms of loss reduction and power flowing through the SB, even though it is upstream, i.e. the minus sign on the SB PF. Moreover, when examining the overall table, though from study [35] to study [12] the loss reduction is improved, an undetected PFs through the SB either downstream or upstream, reaching a peak, and heading upstream, in study [35].

Therefore, a question is raised whether the ODGP solution is affected by the presence of that RPF, or not, and what is its impact.

In any ODGP solution without the consideration of the RPF issue, it is implied that the DN is assumed to constitute an isolated and autonomous network. Thus, power exchanges between adjacent parts of the grid cannot be modelled and simulated. This paper's contribution is to provide a solution to the realistic modelling of RPF along with assessing its impact to the final solution of the ODGP problem. Appropriate modelling and consideration of possible RPF between the considered DN and other parts of the grid are investigated.

3 Extended test systems

For the needs of this paper, two IEEE test systems have been taken as a reference, the IEEE 30-bus [36] and the IEEE 33-bus [37] test systems. The differences between the two systems were important since there was the need to highlight any dissimilarities when assessing the impact of RPF coming either from radial or meshed grid systems. Owing to its role, the SB has only the characteristic to absorb any net PFs. No extended power exchanges between the power system and the upstream network can be modelled. Thus, as seen in Figs. 1 and 2, an additional bus behind the existing SB was inserted as the new apparent SB.

The impedance of the branch that connects both buses (previous and new SB) represents the 'path' for the upstream grid or the upstream grid itself, while the new SB was inserted for solving the PF on the extended versions of both systems. This Z_{up} impedance could be translated either on the impedance of the adjacent grid or even on the impedance of the transformer that intervenes between the downstream grid and the neighbouring transmission-level grid. Utilisation of this proposed 'path' allows the expansion of the examined DN's boundaries in terms of permissible power exchanges between the downstream and the upstream parts of the grid.

Since the upstream grid conditions are supposed unknown in our paper, the impedance of the upstream grid was taken equal to Table 2 values for both systems in order to cover a wide range of scenarios regarding the upstream conditions. In fact, the input impedance is calculated under the clarification that its maximum value should produce the maximum acceptable voltage drop (10%) under the initial rating resulted from the initial load flow.

The other values are calculated as submultiples of the per unit value. Higher impedance values were not examined due to the fact that they could not be modelled without violating the voltage limit constraints of the system.

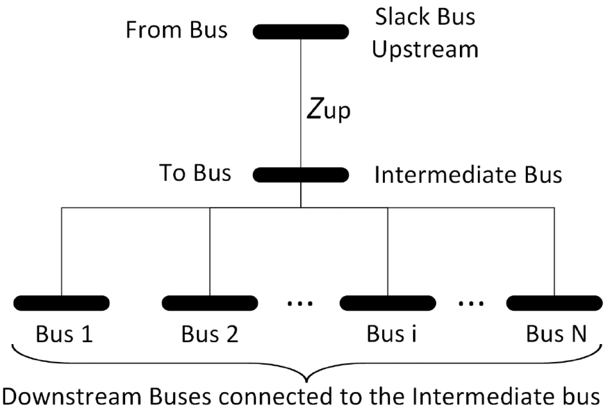

Fig. 3 *SB modification – RPF modelling*

Furthermore, RPF was taken equal to different values as well, starting from 0, i.e. no RPF is allowed and climbing up to 2.5, which means an RPF equal to 250% of the corresponding downstream PF under initial PF conditions for both systems. The downstream PF under normal conditions in the initial systems equals to 25.9 and 3.93 MW for the IEEE 30-bus and IEEE 33-bus, respectively; therefore, the value of RPF in MW for both systems can be found in Table 3. Five different values of Z_{up} and seven different values of RPF result in 35 scenarios examined on each test system.

These levels are chosen to detect the impact of RPF on the solution in terms of penetrated DG capacity along with the distribution of this capacity to accordingly sited and sized DG units. The basic concept of this analysis relies on providing the DN operator with various alternatives regarding the penetration level of DG in a DN along with the dispersion level of these units that result in specific possible loss reduction.

4 Mathematical formulation

4.1 Mathematical model – problem formulation

The current problem is a mixed-integer NL (MINL) optimisation problem. It consists of an NL OF with NL constraints. It can be expressed, in general, as follows:

$$\begin{aligned}&\text{minimise } f(x)\\&\text{subject to } g(x) = 0 \text{ equality constraints}\\&h(x) \le 0 \text{ inequality constraints}.\end{aligned}$$

By converting both equality and inequality constraints into penalty terms $\Omega(x)$, and therefore added to form the penalty function $P(x)$ as described in (1) and (2)

$$P(x) = f(x) + \Omega(x) \tag{1}$$

$$\Omega(x) = \rho\{g^2(x) + \max(0, h(x))^2\} \tag{2}$$

where ρ is the penalty factor.

By using the penalty method of [32, 38], the constrained optimisation problem is transformed into an unconstrained optimisation problem in which the above penalty function is minimised.

4.2 Objective function

In this paper, the power loss function is set as the OF F_{loss}. The power loss can be expressed as follows:

$$F_{\text{loss}} = \min \sum_{\substack{i,\, j=1\\ i \ne j}}^{n_l} g_{i,\,j}(V_i^2 + V_j^2 - 2V_iV_j\cos(\theta_i - \theta_j)) \tag{3}$$

Table 3 RPF magnitude in MW for all scenarios

Scenario number	RPF multiplier	IEEE 30 bus	IEEE 33 bus
#1	0	0	0
#2	0.25	6.48	0.98
#3	0.50	12.95	1.97
#4	1.20	31.08	4.72
#5	1.75	45.33	6.88
#6	2.125	55.04	8.35
#7	2.50	64.74	9.83

where n_l is the number of lines of the network, $g_{i,\,j}$ is the conductance of line i–j, V_i, θ_i and V_j, θ_j are the voltage and angle of buses i and j, respectively.

4.3 System constraints

4.3.1 Equality constraints – PF equations: The constraints, which the OF is subject to, are formed as equality and inequality constraints and are mentioned below. In addition, the constraint regarding the RPF is developed. As equality constraints the PF equations are used

$$g_P(V, \theta, \boldsymbol{P}_{\text{g}}) = \boldsymbol{P}_{\text{bus}} + \boldsymbol{P}_d - \boldsymbol{C}\boldsymbol{P}_{\text{g}} = 0 \tag{4}$$

$$g_Q(V, \theta, \boldsymbol{Q}_{\text{g}}) = \boldsymbol{Q}_{\text{bus}} + \boldsymbol{Q}_d - \boldsymbol{C}\boldsymbol{Q}_{\text{g}} = 0 \tag{5}$$

where $\boldsymbol{P}_{\text{g}}$ and $\boldsymbol{Q}_{\text{g}}$ are the vectors of the active and reactive power generations, $\boldsymbol{P}_{\text{bus}}$ and $\boldsymbol{Q}_{\text{bus}}$ are the vectors of the load flow calculated active and reactive powers, $\boldsymbol{P}_d$ and $\boldsymbol{Q}_d$ are the vectors of active and reactive powers of the loads, and $\boldsymbol{C}$ is a sparse matrix. The (i,j)th element is 1, if generator j is located at bus i, and 0 otherwise.

4.3.2 Inequality constraints: variable limitations: As inequality variables, bus voltages and line thermal limitations have been considered, that is

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{6}$$

$$I_j \le I_j^{\max} \tag{7}$$

where $V_i^{\min}$ and $V_i^{\min}$ are the voltage limits of bus i and $I_j^{\max}$ is the thermal current magnitude limit of line j.

For the extended test case study, where an equivalent of the upstream distribution/transmission system has been added, the SB of the original test case, now a no load PQ type bus, renamed as the intermediate bus (IB), is considered to allow upstream PF of certain amounts of power, reflecting specific permissible RPF in the system, while the algorithm maintains the same goal as before, i.e. to minimise power losses for the original DN (i.e. without considering the new branch with the new bus). The formulation follows in Fig. 3, which focuses on the SB area:

$$P_{\text{IM}\to\text{U}}^{\text{Perm}} \le \text{perc}\Delta P \cdot P_{\text{IM}\to\text{D}}^{\text{Init}} \tag{8}$$

where $P_{\text{IM}\to\text{U}}^{\text{Perm}}$ is the net active power permitted to flow upstream the IB, percΔP is the permissible percentage of the initial active power, and $P_{\text{IM}\to\text{D}}^{\text{Init}}$ is the net active power initially flowing downstream from the IB.

4.4 Penalty function

The penalty function of (1) is formulated as follows:

$$P(x) = F_{\text{loss}} + \Omega_P + \Omega_Q + \Omega_V + \Omega_L + \Omega_{\text{RPF}} \tag{9}$$

where

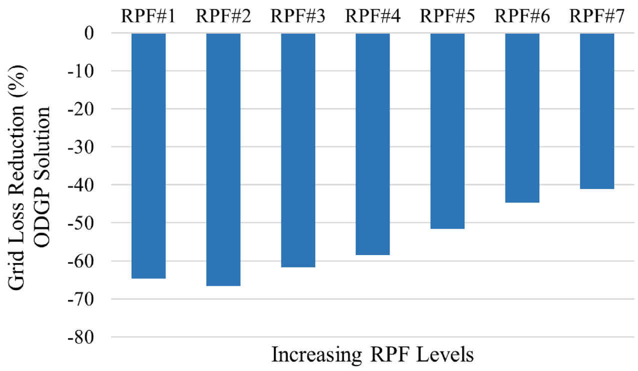

Fig. 4 *Impact on losses reduction (%) for increasing RPF levels*

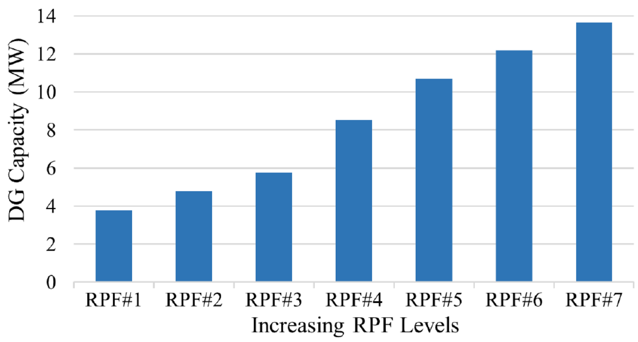

Fig. 5 *Installed capacity of DG (MW) for increasing RPF levels*

$$\Omega_P = \rho \sum_{i=1}^{n_b} g_P(V, \theta, \boldsymbol{P}_g)^2 \quad (10)$$

$$\Omega_Q = \rho \sum_{i=1}^{n_b} g_Q(V, \theta, \boldsymbol{Q}_g)^2 \quad (11)$$

$$\Omega_V = \rho \sum_{i=1}^{n_b} \max\,(0,\, V_i - V_i^{\max})^2 + \sum_{i=1}^{n_b} \max\,(0,\, V_i^{\min} - V_i)^2 \quad (12)$$

$$\Omega_L = \rho \sum_{j=1}^{n_l} \max\,\left(0,\, I_j - I_j^{\max}\right)^2 \quad (13)$$

$$\Omega_{\text{RPF}} = \rho[\,\max\,(0,\, P_{\text{IM}\to\text{U}}^{\text{Perm}} - \text{perc}\Delta P \cdot P_{\text{IM}\to\text{D}}^{\text{Init}})]^2 \quad (14)$$

where n_b is the number of network buses.

4.5 PSO technique

Loss minimisation is an MINL optimisation problem, subject to several constraints, while the problem dimensions could be significantly increased for the ODGP problem. Analytical and numerical approaches could be complex and time consuming [23]. Therefore, in this paper PSO is implemented due to its ability to provide efficient solutions under minimum computational effort. PSO was introduced in 1995 [39], inspired by the social behaviour of bird flocking, or fish schooling. Several versions have been developed since then [40–43]. In this work, the LPSO is applied [35], using the contemporary PSO [44]. The latter is used due to its implementation of the constriction coefficient [35], rather than the inertia weight, because it leads to better and faster results, in the field of ODGP. Moreover, a dimension-dependent-maximum speed is utilised to avoid swarm explosion, enhancing the algorithm altogether.

The neighbourhoods' formulation is described in detail in [45]. The main idea is the reduction of the global information exchange scheme to a local one, where information is diffused only in small parts of the swarm at each iteration. More precisely, each particle assumes a set of other particles to be its *neighbours* and, at each

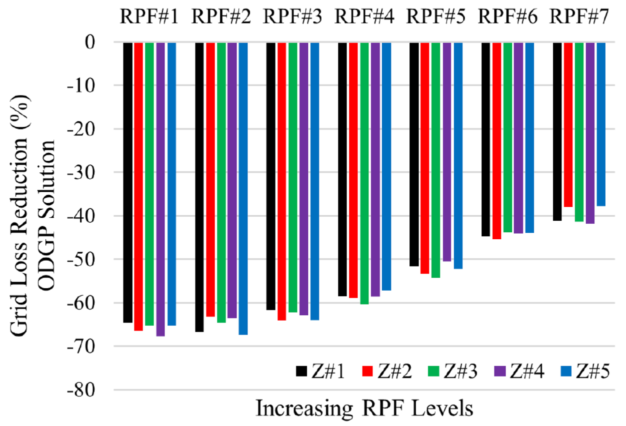

Fig. 6 *Grid loss reduction (%) for increasing RPF levels and different* Z_{up}

iteration, it communicates its best position only to these particles, instead of to the whole swarm. Thus, information regarding the overall best position is initially transmitted only to the neighbourhood of the best particle, and successively to the rest through their neighbours.

Therefore, by introducing the concept of neighbourhoods in this paper, the entrapment risk in local minima is most likely to be avoided, and a better balance of exploration/exploitation of the solution space is achieved.

5 Results

As previously discussed, the proposed methodology along with the respective algorithm has been applied to both the extended versions of IEEE 30-bus and IEEE 33-bus systems. Both systems are extended by means that behind the SB of each system an adjacent grid is assumed that is modelled with its correspondent apparent impedance (Z_{up}) and by downgrading the original SB to an IB, since a new bus behind Z_{up} acts as the new SB. Upstream grid conditions are subject to variations, thus cannot be predicted for all times. Therefore, Z_{up} does not represent the energy equivalent circuit. It is a method which enables us to model the PF and the losses on the upstream grid as well as the grid conditions behind the SB through the downstream system perspective as well. To cover a wide application spectrum, in this paper, five different values for this impedance are examined, as briefly discussed in Table 1. Furthermore, in order to conduct an RPF sensitivity analysis on the ODGP problem, seven different RPF scenarios are considered, i.e. from 0 RPF to 64.75 and 9.75 MW for the IEEE 30-bus and IEEE 33-bus systems, respectively (see Table 2). Consequently, the ODGP problem considering RPF toward loss minimisation is studied for two systems and for 35 different scenario combinations on each system.

5.1 Radial networks

Results for the radial IEEE 33-bus are shown in Figs. 4–6. First, it is shown that for a specific value of Z_{up}, which represents the upstream grid conditions, increasing RPF results to reduced power loss savings succeeded by solving the ODGP problem.

For example, as seen in Fig. 4, for the first value of the Z_{up} examined (equals 0.05) moving from the scenario where no RPF allowed to the one that corresponds to RPF equal to 2.5 times the initial downstream PF will be translated to reduction of the savings percentage from 65 to 41%. This makes sense since pushing the extended test system to succeed such an extreme RPF (250% higher than the initial downstream PF) is translated to a very large penetration of DG; therefore, in additional transmission losses in the downstream system. However, it is of great importance to mention that, for all examined apparent impedances, and for RPF up to 175% of the initial downstream PF, the power savings are reduced, not considerably, though. In some occasions actually (see Fig. 4, for RPF equals 0.25), RPF leads to an even higher saving percentage. The above result shows that RPF does not necessarily

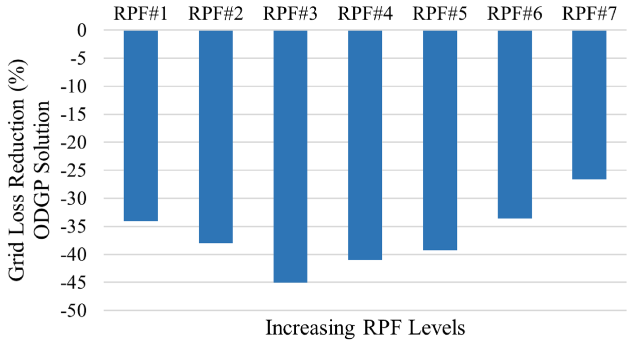

Fig. 7 *Impact on loss reduction (%) for increasing RPF levels*

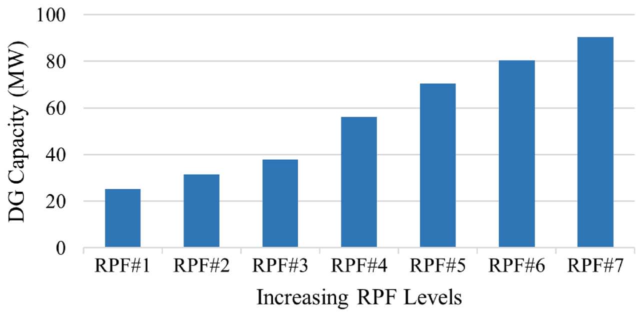

Fig. 8 *Installed capacity of DG (MW) for increasing RPF levels*

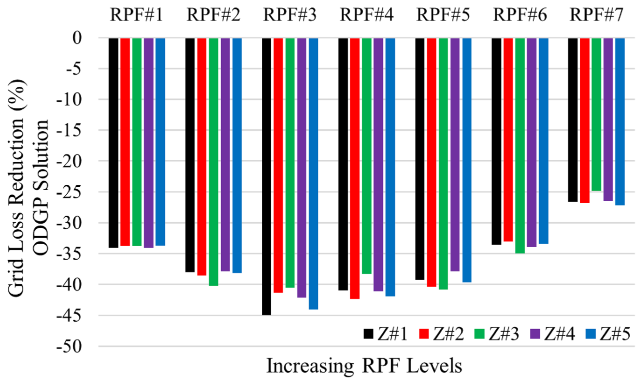

Fig. 9 *Grid loss reduction (%) for increasing RPF levels and different Z_{up}*

have a negative impact on the savings succeeded by the integration of DG.

Second, since for all 35 combinations examined, the ODGP solution corresponds to the sizing and siting of DG units, it is important to highlight the total power of the DG units to be installed compared with the different RPF and the final savings. As it is indicated through our research, for any Z_{up} value, the increase of RPF leads to additional DG capacity to be available for installation. Fig. 5 shows, for the first value of the Z_{up} examined, how DG capacity could be increased as the RPF is getting higher as well. What is important to mention though, is that, regardless the Z_{up} level, while reaching the higher RPF levels (up to 175% of the initial downstream PF) it will result in an insignificant reduction of the power savings on the one hand but on the other it produces considerably higher availability of DG capacity, reaching an increase of 180% (from 3.8 to 10.7 MW). Taking into account that power savings are not affected considerably by allowing such an RPF, this is really important, especially from the aggregator's perspective, since additional installed capacity could provide several benefits such as reliability improvement and others.

Third, as seen in Fig. 6, for the same RPF (or even for no RPF allowed) the importance of the Z_{up} impedance that represents the grid conditions behind the original SB is proved to be insignificant. This leads us to the conclusion that upstream grid conditions do not affect notably the allowed RPF level or the power savings achieved through the ODGP problem solution. Additionally, it is rational to assume that this RPF will constitute power injection to the upstream grid, and thus the downstream grid behaves as an additional power unit for the upstream part of the grid. Such power exchange between adjacent parts of the grid, due to different DG and renewable energy sources (RES) penetration levels into them, should be further examined.

5.2 Meshed networks

Results for the meshed IEEE 30-bus are shown in Figs. 7–9, whereas in Table 4 the ODGP solutions for this test system for the first Z_{up} scenario and all different levels of RPF in more detail are presented.

First of all, the power savings succeeded through the ODGP solution with the addition of Z_{up} and the new SB have a significant difference when compared with the non-extended (original) IEEE 33-bus test system. The scenario as shown in Fig. 7 represents the dependence of the total grid loss savings for different RPF levels, for the smallest examined value of Z_{up}, whereas the ODGP solutions for that particular case are presented in detail in Table 4. However, the same applies for all examined Z_{up} impedances as well. For RPF up to 175% of the initial downstream PF, power savings (loss minimisation) could be further improved in respect to the scenario with no RPF. Regardless the Z_{up} impedance of the upstream grid, pushing RPF to levels 50% or even 120% of the original downstream flow results in increased power savings (from 34 to 45%). Furthermore, going even further, RPF up to 250% of the downstream PF tends to slightly worsen the results but they are still comparable with the initial ones when no RPF was assumed. This conclusion, in addition to the corresponding one from the IEEE 33-bus system, comes to confirm that managing the RPF allowance to the upstream grid does not only necessarily reduce the power losses minimisation succeeded by the ODGP solution but especially in meshed networks could further increase them. Meshed networks are better candidate systems to allow RPF since by design there are more alternative routes to distribute possible increased PFs and congestions that could lead to increased transmission losses.

Second, similarly to the IEEE 33-bus system, it is expected that in order to achieve such RPF levels, increasing installations of DGs need to be implemented. For example, as seen in Fig. 8, for the first examined Z_{up} (the same applies regardless the Z_{up} impedance), reaching RPF levels of 175% results in two significant advantages, additional reduction of losses by ∼6–7% and three times more available DG capacity that can positively affect the system's reliability.

Finally, as in IEEE 33-bus system, the analysis illustrates in Fig. 9 that no great differences appear for all examined Z_{up} levels. This comes to confirm that when the RPF is modelled as explained here and for all these different examined RPF levels, surrounding conditions do not play a significant role in the results. This is because these conditions are utilised in order to model the upstream part of the grid along with the power inlets from the downstream part of the grid but the OF is optimised only for the downstream part.

6 Conclusion

In this paper, the impact of RPF on the solution of the ODGP problem is explored. First, effective modelling of the RPF is discussed and a detailed methodology on how to overcome modelling obstacles such as the one introduced by the SB characteristic is presented. The ignorance of the adjacent to the grid under study conditions led us to develop a new extended SB model for a wide variety of neighbouring conditions, while the analysis was conducted on both radial and meshed grid systems. Second, the modelling concept of the RPF in existing grid systems using a respective grid extension is introduced. Moreover, assessing the impact of RPF to the ODGP problem for both radial and meshed grid networks proved to be significant, especially when viewed from the aggregator's perspective. More specifically:

Table 4 ODGP solutions for first Z_{up} and all RPF levels as applied to IEEE 30 bus

Bus number[a]	Power installed, MW						
	RPF#1	RPF#2	RPF#3	RPF#4	RPF#5	RPF#6	RPF#7
01	SB	SB	SB	SB	SB	SB	SB
02					0.16		0.13
03			1.09				15.75
05						10.55	
07	4.90	3.18		16.99	9.54	5.93	0.43
08				0.28			9.29
09					6.96		
10	2.97	18.72	18.79		10.59		10.15
11				0.01	4.64	22.81	24.38
12				0.01			
14							0.39
17	5.14			18.39	5.29	22.99	8.87
18					2.71		5.49
19	12.14	9.64	11.50	20.18	8.60	11.70	
20							6.38
21					7.49	1.61	
23					0.01		
25				0.08			
26				0.19	1.76		
28					9.29		
29					0.81		
30			6.48	0.01	2.62	4.75	9.09
total *P*, MW	25.14	31.54	37.86	56.14	70.47	80.35	90.26
loss reduction, %	−34.09	−38.01	−45.02	−40.95	−39.29	−33.55	−26.57
RPF, MW	0	−6.49	−12.99	−31.17	−45.45	−55.19	−64.93

[a]Buses 04, 06, 13, 15, 16, 22, 24, and 27 do not host any DGs for all scenarios.

- RPF up to a level will not negatively affect the ODGP solution toward loss minimisation. Especially for meshed networks, allowing RPF can improve the power savings.
- Allowing RPF, when not affecting the power savings achieved by DG installations, results permit the exploitation of all possible advantages provided by additional DG capacity. Meshed networks are better candidate networks to allow RPF since the additional alternative branches could distribute high PFs to the system topology.

As indicated by the results, calculating the ODGP problem solution without considering the impact to the neighbouring grids can lead to either a sub-optimal solution or, even worst, to a solution that reduces grid losses on the downstream network but in reality, simply transfers the loss issue as externality to the surrounding networks. Finally, as indicated, the existence of managed RPF allowance may further improve the solution to the ODGP problem.

7 References

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