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Full Length Research Paper

Virtual power plant (VPP) and economic dispatch (ED)

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In this paper, general concept of a virtual power plant (VPP) and its model is developed. In the proposed model for the VPP, power system is divided into smaller subsystems, and it is called the power system cells. Each cell is a small network that has a control center and management system. The concept of VPPs includes multi-cell power system with a flexible control and management functions for the system. In this paper, in order to model proposed VPP standard system (IEEE 30 bus test system) is used. First, function of each power system cell is defined based on references and constraints and apply the above planning application; MATLAB and General Algebraic Modeling System (GAMS) software have been used until the results load flow and economic dispatch (ED) can be compared. In this project, genetic algorithms (GA) have done optimization of power plants using a cost function and the results compared.

Key words: Virtual power plants (VPP), economic dispatch (ED), micro network, load.

INTRODUCTION

The structure of distribution network located on virtual power plant (VPP) area, the location of loads, generation units, the other constituent parts and the connections to the distribution network is shown in the Figure 1.

As shown in Figure 1, central controller coordinating (CCC) is responsible for coordinating between cell powers in the VPP (Heiko, 2005).

VPP structure in this paper is considered by IEEE 30 bus test system. Load flow, economic dispatch (ED) and optimization cost functions for the VPP are solved by genetic algorithm (GA) with MATLAB and General Algebraic Modeling System (GAMS) software.

DESCRIPTION OF VPP STRUCTURE

Figure 2 shows the proposed distribution network including VPP, distribution system, loads and other components.

In this paper, VPP structure is studied at standard network (IEEE 30 bus test system) because this system is suitable for verifying the result of load flow, ED and operation system.

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As shown in Figure 2 in this model, the VPP is divided into two subsets (Dielmann and Velden, 2003). They are not physically linked together, but they are linked based on the contract, which has been signed between distribution system controller operator (DISCO), and the VPP. In the other word, they are linked virtually (therefore, this model is called VPP).

In the proposed model, the parameters will define as follows:

1) Virtual power (*P virtually*): The value, which is the power that can be exchanged virtually between tow subsets of VPP,
2) Generated powers of each subset (*P produce*): Total generated power in i_{th} subset of VPP,
3) External power of the i_{th} subset (*Pex_subi*): It includes virtual power with DISCO in this subset,
4) i_{th} subset's Load (*Load_subi*): Total load in i_{th} subset.

The definition of consist components in suggested model (Figure 2) is presented as follows:

Micro networks

Micro network is a low voltage distribution network (LV), which includes distributed generation system (DG),

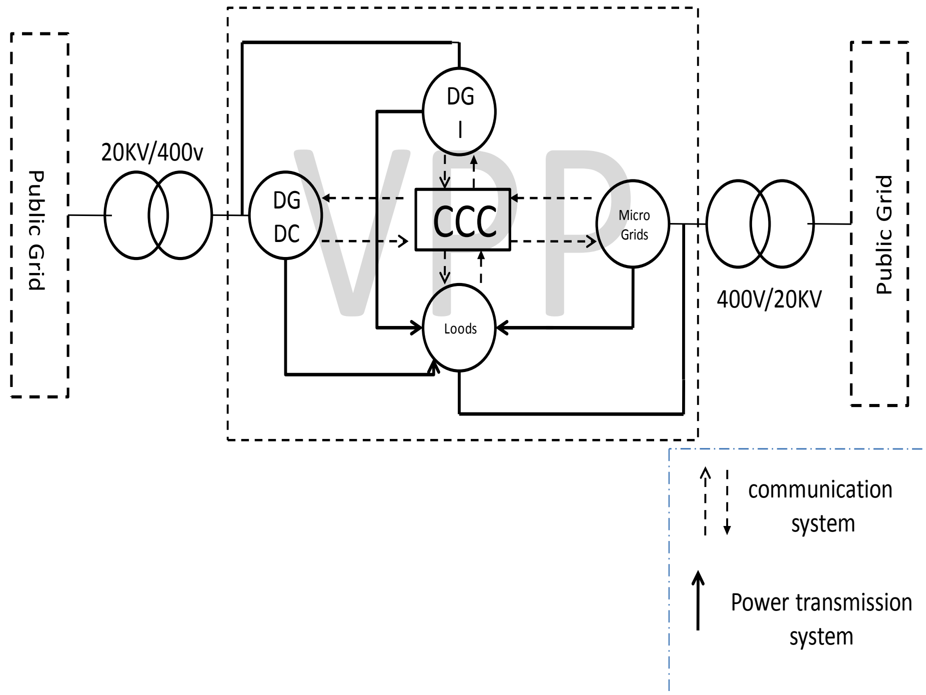

Figure 1. Schematic of internal communications and components of a VPP (Moghaddas and Tafreshi, 2010).

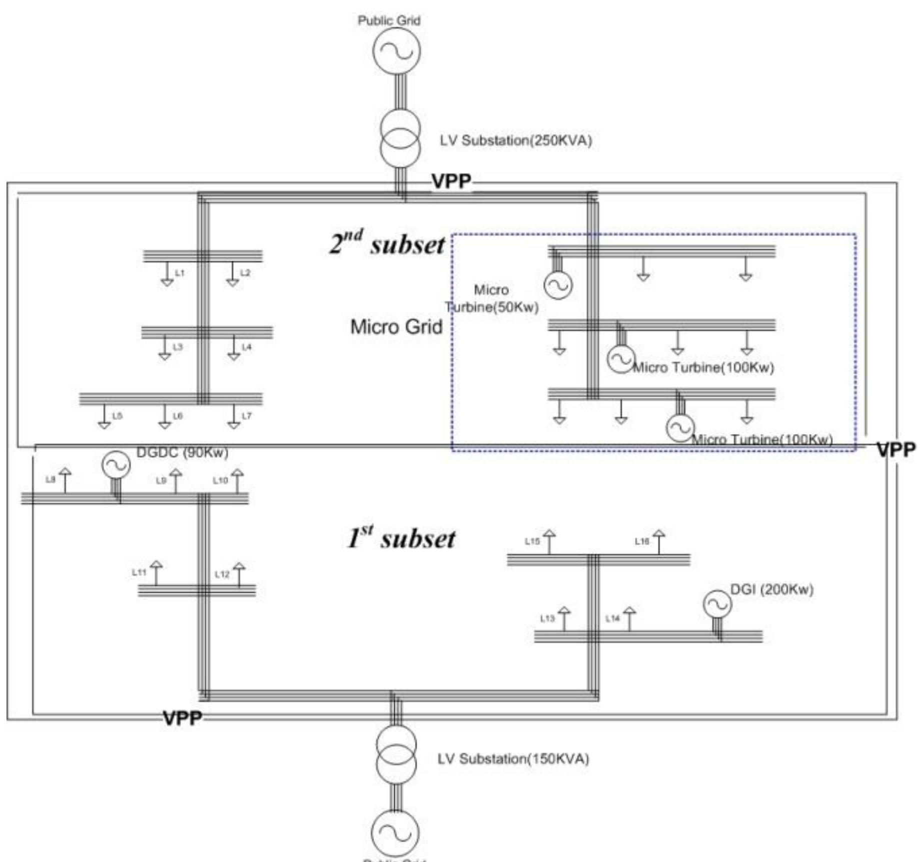

Figure 2. VPP structure (Moghaddas and Tafreshi, 2010).

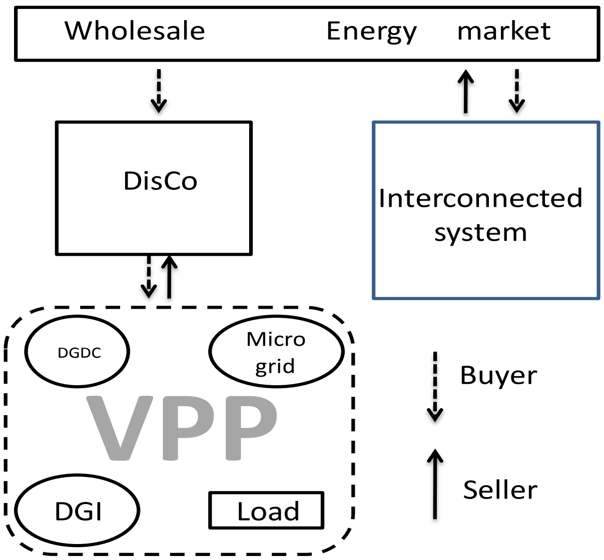

Figure 3. Transaction between VPP and DISCO market.

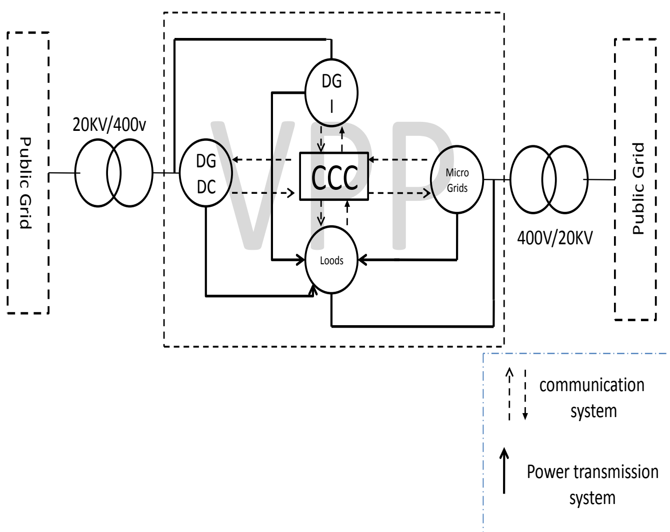

Figure 4. Technical transactions within the VPP.

energy storage units and consumers, connected to network as loads (Christian et al., 2006; Pudjianto et al., 2008).

This system can be connected with the main distribution network or can be isolated from main distribution network (island mode). In proposed model of micro network, network system is connected to the network.

All units are in communication with micro network management which is responsible for imposing the control and management strategies on the system by telecommunication equipments.

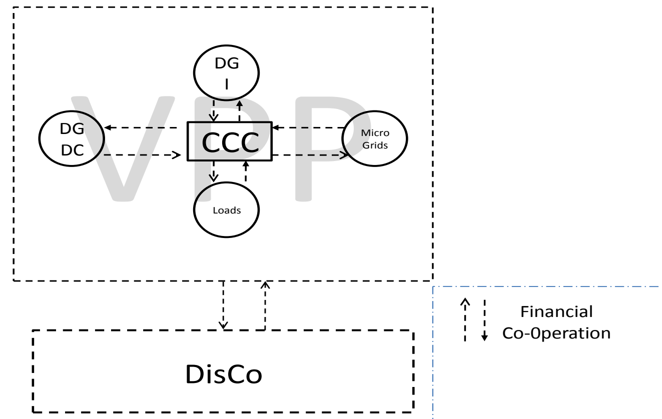

Figure 5. financial transactions within the VPP.

DGI unit

These producers have private properties and they work independently from VPP management. These units participate in the VPP and present their markets (in the form of tables) to CCC (Palma-Behnke et al., 2005; Pudjianto et al., 2007).

DGDC unit

According to DGDC, one of VPP units, for optimal utilization, needs to report the cost of energy production and its status to CCC (Bignucolo et al., 2003; Caldon et al., 2004).

Load

Load within the scope of VPP, are categorized, as none-critical and critical. CCC is responsible for estimation of loads.

The transaction between VPP and DISCO is shown in Figures 3, 4 and 5. In the proposed model in this paper, in order to optimize the benefits and supply the subset's loads, VPP will participate in DISCO

DGI and micro network propositions will be suggested hourly and DGDC's production costs and amount of producible power will be provided as tables to CCC.

CCC also has the task of holding the local markets for VPP. Besides, CCC manages interruptible loads and also will determine unsupplied loads costs, of customers.

CCC has important tasks, such as energy dealing with the upstream networks, DGI and micro network. Besides, it provides energy for all components of VPP in all connection nods and need to be in a defined and acceptable zone of power factor. Also, voltage profile needs to be in a permitted range.

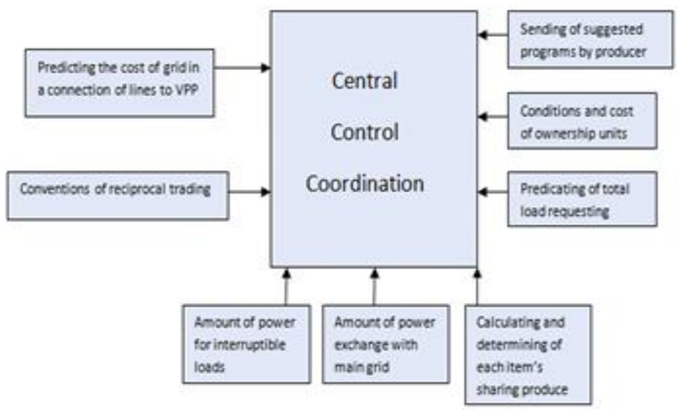

Figure 6. The performance of CCC in the proposed model.

ESSENTIAL COORDINATION FOR TECHNICAL AND FINANCIAL TRANSACTIONS

In this model, VPP is working in order to supply the loads (which are in VPP area), by concentration in maximizing the VPP's profit (João Tomé Saraiva Markets and Regulation, 2007).

The VPP will gather suggestions and prices information of participated companies in the market as follows:

a) CCC need to be in formed by DGI about the proposed schedule of this unit (DGI) which need to be set in the forms of tables for 24 h .
b) These tables contain the maximum amount of available and disposable power of VPP plant and its specific price for any hour of the day and night. Same as DGI, micro network need to inform CCC about schedule which is proposed by this unit (in the form of 24 h tables). In is noteworthy to mention that in proposed model, producers will be controlled independently, controlled by VPP and their ownership is not dependent on VPP. In the transaction of these units with VPP, they will be paid individually for the maximum amount of disposal, produced power of VPP and the exchanged energy (with VPP). This strategy will reduce the probable failure in the presents of the severity of potential losses, in upstream market. This requirement is determined by the contract, which it signed between VPP and producers (whom are under the control of VPP), and this is one of the advantages of VPP towards owning the control of producers with independent ownership specifying the conditions of DGDC unit owned by VPP. This units report the costs of energy production and the amount of producible power of these units to CCC directly. These costs include startup and operation costs and due to these costs, CCC will calculate the production plane of this units then send it back to them.
c) Prediction of following day's load, which should be done by CCC: This prediction is consisting of two separated parts:

1) Prediction of critical loads (loads that cannot disconnected),
2) Prediction of none-critical loads (loads that can disconnect).

In this prediction, the minimum amount of power, provided by VPP, is considered. This amount represents the non-disconnected loads and same as the others. This information needs to be reported to CCC, in the form of 24 h table. It is worth mentioning that the price of energy sold to consumers, is constant and have a certain amount for each hour of night or day.

The amount or price of purchased energy (from DGI and micro networks) or sold energy (to DISCO) needs to be determined by mutual contracts (at each dot) and it need to be reported in the form tables to CCC. CCC will predict the cost of next day (24 h) in two communication dots (between main network and VPP). It will make it possible for CCC to determine the contribution of each producer according to his priorities.

The performance of center of coordination and control of the VPP (CCC) is shown in Figure 6.

METHOD

Mathematical model for optimal operation of the VPP

Presented model will be solved for 24 h period by mathematic optimization problem.

Due to the fact that in competitive markets, maximization of profit is the main purpose, therefore:

Max Z = $f(x)$

Sat. $g(x) = 0$

$h(x) \leq 0$

$xmin < x < xmax$

Where: $f_{(x)} = \sum_{i=1}^{24} P_{load1i}\, p_{load1i} + (P_{load2i} - P_{uki})\, p_{load2i} + P_{ex1i}\, p_{ex1i} + P_{ex2i}\, p_{ex2i} - P_{mici}\, p_{mici} - P_{DG1i}\, p_{DG1i} + P_{Bisi}\, p_{Bisi} - P_{Bipi}\, p_{Bipi} - C_{uki}\, P_{uki} - C_{DGDCi} - (P_{micpri} + P_{DGIpri})$

Represents the goal function in the optimization problem of exploiting the VPP in market.

DGDC cost modeling

In the module of VPP, investigated in this paper, DGDC is a fuel cell. The costs of generated energies by this unit can be calculated as follows:

$$C_{DGDC} = \alpha + \beta P_{DGDC} + \Upsilon P_{DGDC}^{2} + [(\alpha_{e1} + \beta_{e1}(1 - e^{-Toff/\dagger}))^{*} u_i (u_i - u_{i-1})]$$

In the mentioned cost function, first part is related to consume fuel and generator maintenance costs.

Second part function is related to startup costs of unit where, it is a function of shutdown time of generator (t_{off}) and U shows the ON/OFF condition of generator in the I_{th} hour.

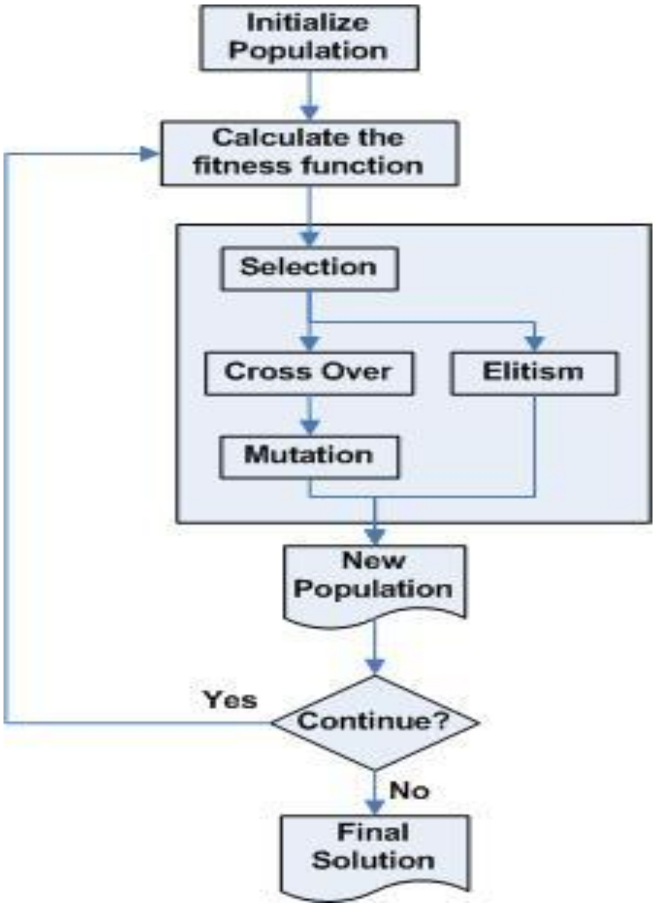

Figure 7. Flowchart of optimization by genetic algorithm.

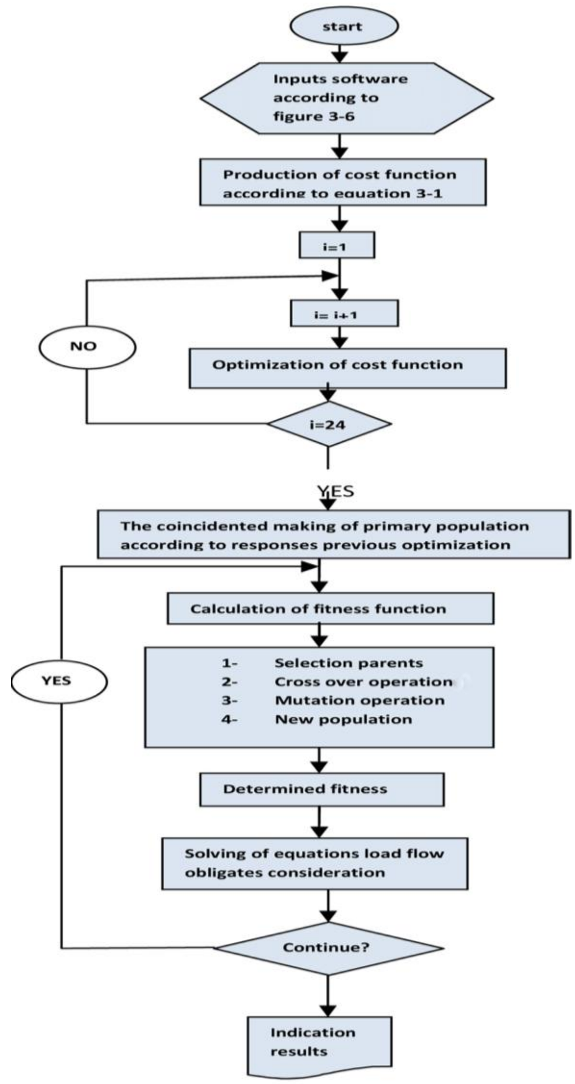

Figure 8. Flowchart of optimization VPP.

In order to define α, β and Υ parameters in the first part, the amount of input fuel and its cost need to be determined. As an example, in order to produce 1 KWH energy and for a turbine with 250 kW power, 12,645 Btu will be needed. Due to the cost of energy in different parts of the world, the cost of system input energy need to be determined.

In the cost function of this unit, it is noteworthy that the costs of initial investment, installation, vector, and maintenance are calculated in the mentioned function (the unit is $/H)

Balance of the power (E, NL)

The active power needs to be balanced in all nodes and sheens of distribution unit, which are related to VPP in next 24 h.

This constraint is shown in the following equation:

$$P_{loadi} + (P_{loadi} - P_{uki}) + P_{ex1i} + P_{ex2i} + P_{Bisi} = P_{DGDCi} + P_{mici} + P_{DGIi} + P_{Bip}$$

Where *i= 1,2,3,….,24*

The limitations between distributions lines (NL, NE)

Indicated limitations are the limitations of current power in distribution lines. In order of consideration of this constraint in each VPP's distribution network lines, two ways are recommended in this paper. The limitations of current active power in line $\overline{P}ij$ considered as follows:

3-5) $Pij \leq Pij\ max$

3-6) $|I_{ij}|^2 \leq |I_{ij\ max}|^2$

DGDC unit's limitations

A) Power producing limitations: *Qmin ≤ Q ≤ Qmax*

B) Constraints of the minimum units off/on time: The constraint of the minimum on time of the unit is an operational constraint and it is defined in the following equation:

$$(T^{on}_{j-1} - MUT)(U_j - U_{j-1}) \geq 0.0$$

Where T_{on} is the on time of unit in J_{th} hour, MUT is the minimum on time of unit and U is the on/off condition of the unit (U=0 then the unit is off, U = 1 the unit is on).

The constraint of the minimum of time will be defined as follows

$(T^{off}_{j-1} – MDT) (U_j – U_{j-1}) \geq 0.0$

Where, T^{off} is the Units off time and MDT is minimum permitted unit off time.

C) Ramp rate constraints: Two followings equations are the constraints of minimum and maximum production improving rates:

$Pj – Pj\text{-}1 \leq \Delta P$

$Pj\text{-}1 – Pj \leq \Delta P_D$

Where ΔPu is the maximum variation in production and ΔPD is the minimum production increase rate in J_{th} hour.

Implementation of software development based on GA

As shown in Figure 7, the flowchart-based GA optimization software developed for the model listed is visible in Figure 8. Items that fit the general behavior of the function were defined, and more appropriate method scan be designed for optimization. All stages of the GA in the general case are displayed and shown in Figure 8.

RESULTS AND DISCUSSION

In this article, the optimal operation of proposed VPP, shown in Figure 4, is calculated. This optimization problem is solved using GAMS software and GA in order to achieve expected results (Roberto et al., 2005; Yohan, 2000; Eko, 2007).

The GAMS is a high-level modeling system for mathematical programming problems (Ackermann et al., 2000; Bignucolo et al., 2003). This software is equipped with a language compiler, in addition to several integrated high performance solvers. In this section, the VPP optimization problem is solved with the GAMS software and the results are presented.

Inputs

The approach of this paper entails using a case study solved with GAMS and GA in order to achieve expected results. For modeling confirmation, the results will be compared. In the beginning, the inputs for this case study will be presented. The inputs of both solving methods are the same.

In this case study, these inputs are considered to be valid (11a to d)

$$\rho_{Load1} = 68.5(\$ / MWh) \quad (11a)$$

$$\rho_{Load2} = 55.5(\$ / MWh) \quad (11b)$$

$$C_{uk} = 10.566(\$ / MWh) \quad (11c)$$

Table 1. Micro grid bid fluctuations as inputs of both case studies for 24 h duration.

Time (h)	P_{mic}($/MW)	P_{Maxmic}(kW)
1	29.86	230
2	27.101	240
3	26.626	230
4	25.126	220
5	25.076	210
6	28.491	220
7	29.091	200
8	44.487	200
9	48.126	180
10	51.626	170
11	54.367	180
12	54.726	160
13	55.616	120
14	53.9	120
15	61.126	110
16	63.426	100
17	63.345	-30
18	58.636	-40
19	55.025	-40
20	46.886	140
21	44.126	170
22	38.726	170
23	34.176	220
24	32.426	220

Also, the coefficients used for generating the cost function of DG2 are set to these values.

$$C_p^0(\$/h) = 0,\ C_p^1(\$/MWh) = 30.4 \text{ and } C_p^2(\$ /(MW)^2 h) = 0.01 \quad (11d)$$

The mentioned inputs are assumed to be constant for 24 h duration. There will be some inputs which will fluctuate during 24 h. The fluctuating inputs are shown in Tables 1 to 4.

Model verification and validation

Utilizing these data as inputs for GAMS software, will lead to the results presented in the following way.

The GAMS used these data for solving the optimization problem (Michael et al., 2009). The results will show the optimum situation for achieving maximum profit for the VPP. The GAMS out puts for the case study are shown in Figure 9.

The information, shown in Tables 1 to 4, will be used also as inputs of the case study solving with GA in MATLAB environment (Didier, 2006).

The GA out puts for the case study can be observed in

Table 2. The DG1 bid fluctuations of both case studies for 24 h duration.

Time (h)	ρ_{DGi}($/MW)	P_{MaxDGi}(kW)
1	28.328	175
2	24.808	175
3	25.188	175
4	25.64	175
5	26.643	175
6	27.387	185
7	29.438	185
8	42.288	185
9	46.668	185
10	50.239	195
11	52.467	195
12	52.998	195
13	54.966	195
14	53.288	195
15	61.703	195
16	61.978	195
17	63.255	195
18	57.878	195
19	47.853	185
20	45.638	185
21	43.336	185
22	36.678	175
23	34.088	175
24	31.724	180

Table 3. Market forecasted prices.

Time (h)	ρ_{exi}($/MW)
1	30.149
2	27.291
3	23.364
4	21.964
5	24.057
6	31.757
7	32.45
8	48.284
9	50.594
10	52.994
11	56.244
12	56.394
13	57.904
14	55.314
15	64.014
16	66.484
17	68.134
18	64.764
19	56.504
20	53.444
21	48.444
22	40.584
23	37.894
24	31.404

Figure 10. The results of the GA for the case study shown in Figure 10, illustrates the values which will lead to maximum profit for mentioned VPP. It can be derived that the amount of power that is produced by each generator and trend of its changes are almost the same in both methods. Only in some cases and some hours, they are different. This distinction occurred due to difference in software's accuracy. In addition, total profit for the VPP by GAMS is 295.471 $ for a day and this value by GA is 305.9162 $ for a day, which can be calculated from addition of values in Figure 11.

Solving optimization algorithm with GA

In this part, the optimization problem for VPP is investigated using four parameters: ρ_{Load1}, ρ_{Load2}, C_{uk} and ρ_{pr}. With these parameters, three different scenarios are formed where in each of them one of the ρ_{Load1}, ρ_{Load2} or C_{uk} variable is changed while others are fixed. Other required inputs for this section are the same as that in Tables 1 to 4.

In Table 5, the initial values of the variables for all the scenarios are presented. According to these values, in the next steps, behavior of the model is studied while only one of them is changed.

As mentioned in each scenario, only one parameter will change in a specific rising manner. The outputs are then use to observe the effect of each parameter on the result.

Observation while a price for sensitive loads is changing

While the other parameters are the same as Table 6, the value of ρ_{Load1} is gradually increasing in six district steps. The output of the optimization problem, VPP profit is then obtain from MATLAB using GA method. The result is shown in Table 6.

Observation while a price for non-sensitive loads is changing

The same as previous part, in the second scenario all the parameters are the same as that in Table 6. The changing variable will be ρ_{Load2} which will change in 6

Table 4. Loads forecasting.

Time (h)	P_{Load}	$P_{Load\ 1}$	$P_{Load\ 2}$
1	342.5	286	56.5
2	327.5	291	36.5
3	277.5	251	26.5
4	277.5	251	26.5
5	327.5	286	41.5
6	377.5	336	41.5
7	377.5	316	61.5
8	437.5	361	76.5
9	462.5	371	91.5
10	482.5	391	91.5
11	488.5	382	106.5
12	522.5	411	111.5
13	512.5	401	111.5
14	522.5	411	111.5
15	527.5	401	126.5
16	532.5	406	126.5
17	547.5	391	156.5
18	517.5	366	151.5
19	487.5	346	141.5
20	462.5	346	116.5
21	442.5	351	91.5
22	387.5	296	91.5
23	362.5	286	76.5
24	357.5	291	66.5

steps. The output of GA method, which is the profit of the VPP, is shown in Table 7.

Observation while C_{uk} is changing

In the third scenario, the changing parameter is C_{uk}. The other inputs are the same as that in Table 5. The profit of the VPP obtained from the GA, is shown in Table 8.

Comparing the results for three scenarios

Achieving the results for the mentioned scenarios, it is possible to compare effects of different changing variables and observe their relation with the profit of VPP. In Figure 12, related to the first scenario with GA, it can be noted that the profit of VPP is steadily increasing when the only parameter that changes is ρ_{Load1}. The slope of the profit trend is approximately 8.5 $(MWh/\$^2)$.

In Figure 13, the same graph is plotted for the second scenario. The profit of the VPP is again rising in accordance to the increment of the ρ_{Load2}. But it can be seen that this time the slope of the profit trend, roughly

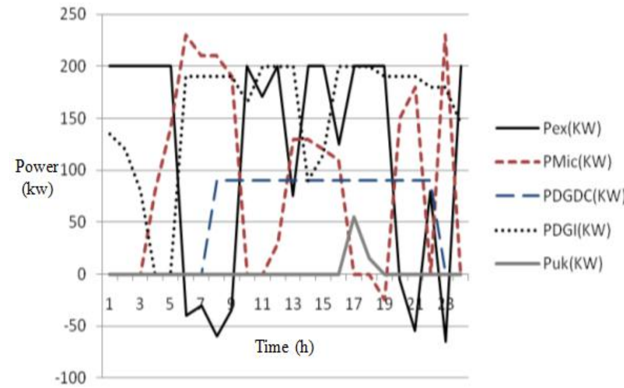

Figure 9. The GAMS out puts for the case study

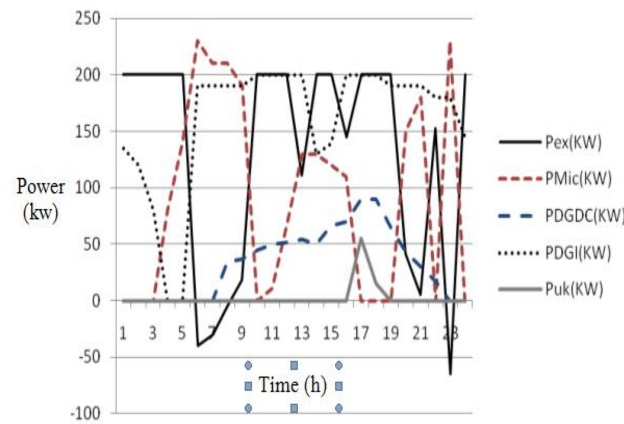

Figure 10. The GA out puts for the case study.

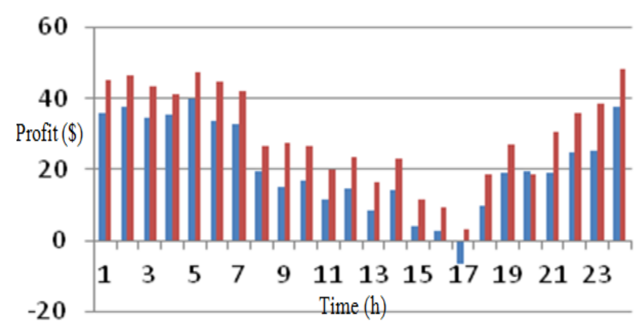

Figure 11. The VPP's hourly profit for each method.

5 $(MWh/\$^2)$, is less than the slope of the graph achieved for the first scenario. Plotting the results for the third scenario is illustrated in the Figure 14. As is depicted by the related graph, the relation between C_{uk} and the profit of VPP is not following the same trend.

Table 5. Initial values of the variables.

Variable	Values ($/MWh)
ρ_{Load1}	72.3
ρ_{Load2}	61.2
C_{uk}	12.86
ρ_{pr}	7.455

Table 6. Out puts of GA according to changes in prices for sensitive loads.

Variable	ρ_{Load1}	Profit($)
Step1	72.3	275. 93
Step2	74.3	296.13
Step3	76.3	318.49
Step4	78.3	328.38
Step5	80.3	336.57
Step6	82.3	361.72

Table 7. Outputs of GA according to changes in prices for non-sensitive loads.

Variable	ρ_{Load2}	Profit($)
Step1	61.2	275.93
Step2	63.2	282. 81
Step3	65.2	291.31
Step4	67.2	306.28
Step5	69.2	313. 97
Step6	71.2	323.62

Table 8. Outputs of GA according to changes in penalty factor for un-served loads.

Variable	C_{uk}	Profit($)
Step1	12.86	275.93
Step2	13.86	271.28
Step3	14.86	267.26
Step4	15.86	267.94
Step5	16.86	281.88
Step6	17.86	276.17

In the beginning, increasing the C_{uk} will cause the graph to fall down slightly. Reaching to the point where the C_{uk} is around 12.5 $(MWh/\$)$, the graph will start to increase and after 13.5 there is a sudden increment till the peak at around 15 $(MWh/\$)$. After this point, there will be a down slope again.

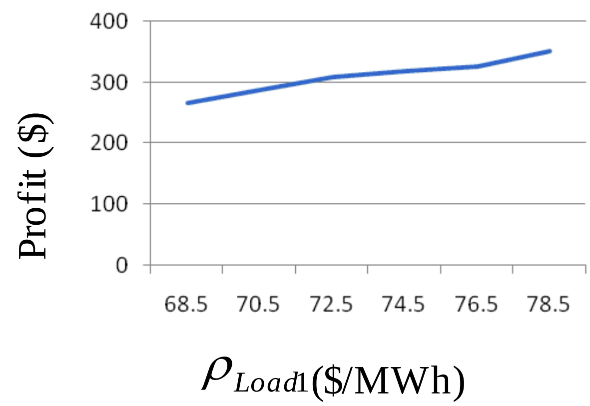

Figure 12. The VPP profit graph of the 1st scenario.

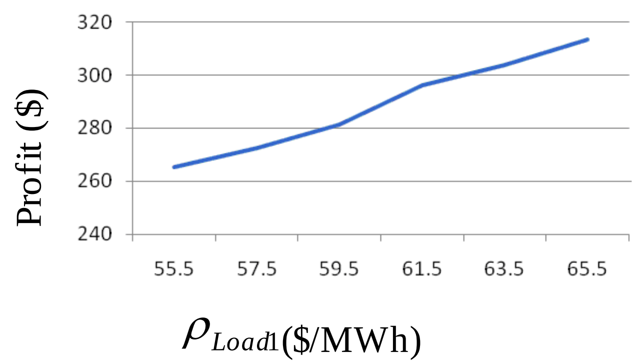

Figure 13. The VPP profit graph of the 2nd scenario.

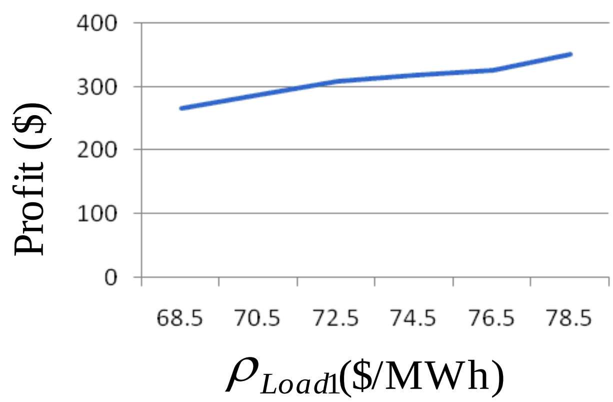

Figure 14. The VPP profit graph of the 3rd scenario.

Conclusion

In this paper, the objective was to present a model that is suitable for gaining maximum profit in VPP. The performance analysis of the model was investigated using two different methods of optimization. The GAMS software, suitable conventional software used for solving mathematical optimization problems, was provided with series of information from the public grid in 1 day duration and performed the expected optimization. For better validation, this operation was done with two different software tools and with the same initial inputs. In both methods, the outputs of the software were in accordance with expected behavior of the model and showed cost efficiency characteristic in power market environment. Afterwards, with the purpose of observing the effect of changes in input parameters, GA was used. In order to provide the GA with productive inputs, each time one parameter was changed in uniform steps while the others were fixed. The effect of parameter changes were plotted and observed.

According to the obtained results from GAMS and GA, it is possible to conclude that the proposed VPP model in this paper is capable of satisfying the required performance maximizing the profit of decentralized distributed power system.

In addition, it should be mentioned that due to flexibility characteristics of this model, it is possible to develop the model in order to manage more DGs, loads and generators. The structured algorithm used for this model, enables the system to easily handle several different types of generation units. Due to separate cost function and constraints of each unit, it is possible to use general form of the model to manage systems with more units. In other words, it is possible to develop the model by branching DG1 in case of new independent DGs, DG2 in case of new DGs owned by VPP and micro grid parameters in case of new micro grids (Oyarzabal et al., 2005). With this model, it is possible to manage hundreds of decentralized generating systems. For the future, it is suggested that more advanced control and communication systems be taken into consideration for better performance of VPP.

ACKNOWLEDGEMENTS

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Summary of description parameters of this paper

$_{load1:}$ The amount of Predicted energy which is for selling to sensitive loads (none Disconnect able)

$p_{load1:}$ The price of sold energy to sensitive loads

$P_{load2:}$ Predicted energy which is for selling to none-sensitive loads

$p_{load2:}$ The price of sold energy to none-sensitive loads ($ / Kwh)

$P_{exj:}$ The amount of exchanged energy between VP and market in J^{th} dot, the sign of this parameter shows purchase (+) or sales (-), ratio to the network.

$p_{exi:}$ The prediction of purchase / sold energy (in the market) in I^{th} hour

$C_{uk:}$ Penalty factor that need to be paid for the power which it did not supplied for sensitive loads ($/Kwh).

$P_{uk:}$the amount of none supplied power of none sensitive loads

$P_{Bipi:}$ Amount of purchased energy from the producers which it determined by mutual contracts

$p_{Bipi:}$ Price of purchased energy from the producers by mutual contracts ($/Kwh)

$P_{DG1:}$ The amount of purchased power from DGI (the amount of this value will be defined by CCC)

$p_{DG1:}$ The amount of purchased power from DGI (the amount of this value will be defined by CCC)

$P_{DG1pr:}$ Amount of expressed power by DGI

$P_{micpr:}$ Amount of expressed power by micro-network.

$p_{pr:}$ The cost, which it needs to be paid for each KW of, expressed power to micro network and DGI (maximum amount of available and producible power disposable for VP) ($/Kwh)

$C_{DGDC:}$ The cost of generated power by DGDC (which it scheduled by CCC) ($/h)

$P_{mic:}$ The amount of exchanged power with micro-network (determined by CCC) in which ± Signs displays the purchase / sale of the network

$p_{mic:}$ The price of exchanged power which micro-network (the Price had determined in suggested table) ($/Kwh)

$P_{Bisi:}$ Amount of energy, which it sold to the DISCO by mutual contracts

$p_{Bisi:}$ Price of energy, which it sold to the DISCO by mutual contracts ($/Kwh)

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APPENDIXES

Table A1. Predication of demanded loads (MW).

Time (h)	P_{load}	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	2nd subset	1st subset
1	360	32	27	22	29	18	36	12	24	21	28	17	23	41	25	5	5	171	189
2	355	30	25	21	31	20	32	10	16	23	28	12	26	39	22	5	10	174	181
3	305	18	21	14	22	18	28	11	12	25	26	12	22	31	18	5	17	137	168
4	305	17	20	13	23	17	26	10	12	24	25	12	20	30	18	4	29	131	174
5	360	20	21	16	24	19	27	15	18	26	28	18	21	36	24	10	27	152	208
6	400	31	26	20	27	23	30	16	22	28	30	20	24	40	26	14	23	173	227
7	400	32	25	21	25	25	28	18	23	28	29	20	25	38	25	14	24	174	226
8	465	35	30	25	28	26	32	22	26	30	30	36	28	40	26	15	31	203	262
9	490	35	32	27	30	28	34	22	28	32	32	38	30	42	28	15	32	213	277
10	505	36	34	28	32	30	36	24	28	34	32	38	34	42	30	17	30	220	285
11	521	35	35	29	32	32	35	25	30	33	33	36	33	42	30	17	34	233	288
12	540	38	36	30	32	33	36	28	32	34	36	40	35	44	32	20	39	228	312
13	530	38	36	30	34	32	34	26	32	34	36	38	35	40	31	20	39	225	305
14	550	36	38	32	32	34	34	28	30	34	35	40	36	40	32	22	42	239	311
15	555	34	35	32	34	38	36	25	28	38	36	42	36	42	33	22	39	239	316
16	560	34	36	34	34	36	38	26	30	40	34	42	35	40	34	22	40	243	317
17	570	29	38	30	35	38	36	38	32	42	36	42	36	42	35	25	36	244	326
18	535	28	34	28	34	35	36	36	29	38	34	40	34	38	33	24	39	226	309
19	510	28	28	30	32	34	34	34	30	36	34	40	34	36	30	24	26	220	290
20	490	27	26	29	27	30	28	30	28	34	32	37	33	34	28	24	38	202	288
21	465	28	26	30	25	28	28	29	30	35	30	35	35	32	26	20	28	194	271
22	410	32	27	22	29	18	36	18	24	25	28	17	25	41	28	15	25	182	228
23	380	30	25	21	31	20	32	16	18	23	28	16	26	39	26	10	24	170	210
24	375	28	23	23	30	22	31	15	20	24	30	15	25	38	24	10	22	167	208

G1 = 0; G2 = DGDC; L2, L3, L4, L5, L7 = L\`8, L\`9, L\`10, L\`11, L\`12; G3 = 0; G4 = DGI; L8 = L\`13+L\`14+L\`15+L\`16; G5 = 0; L1, L2, L3, L4, L5, L6, L7 = L\`16, L\`17, L\`18, L\`19, L\`20, L\`21, L\`22; G6 = GMG power generated with the micro-grid; L12 = Indication total load at micro-grid.

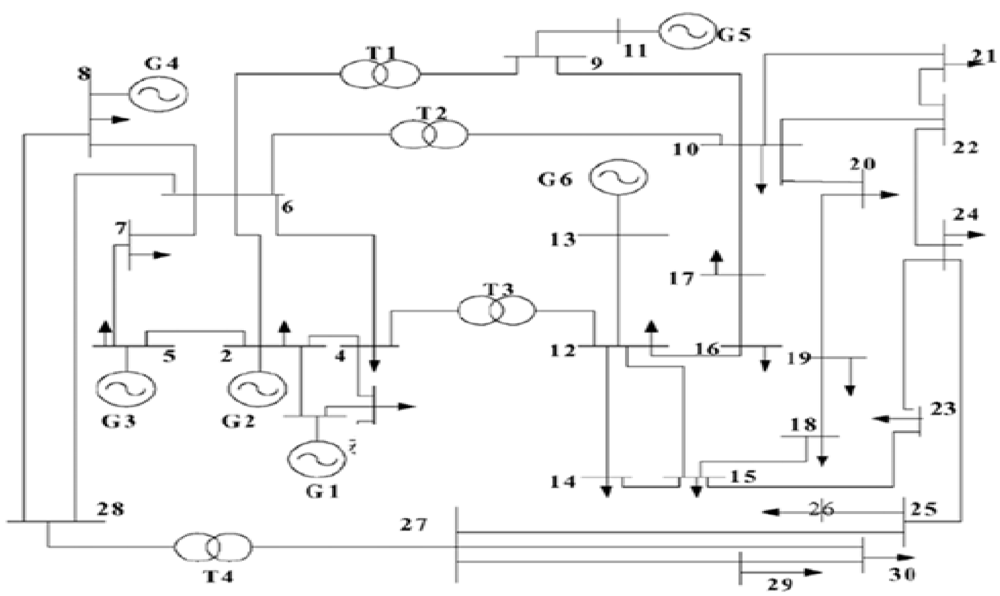

Figure A1. IEEE 30 bus Test System, single line diagram. In Figure 1: general network structure in this paper include loads and generation units which is modeled by IEEE 30 bus standard network for load flow operation and authentic conclusion of VPP model network is used in this paper.

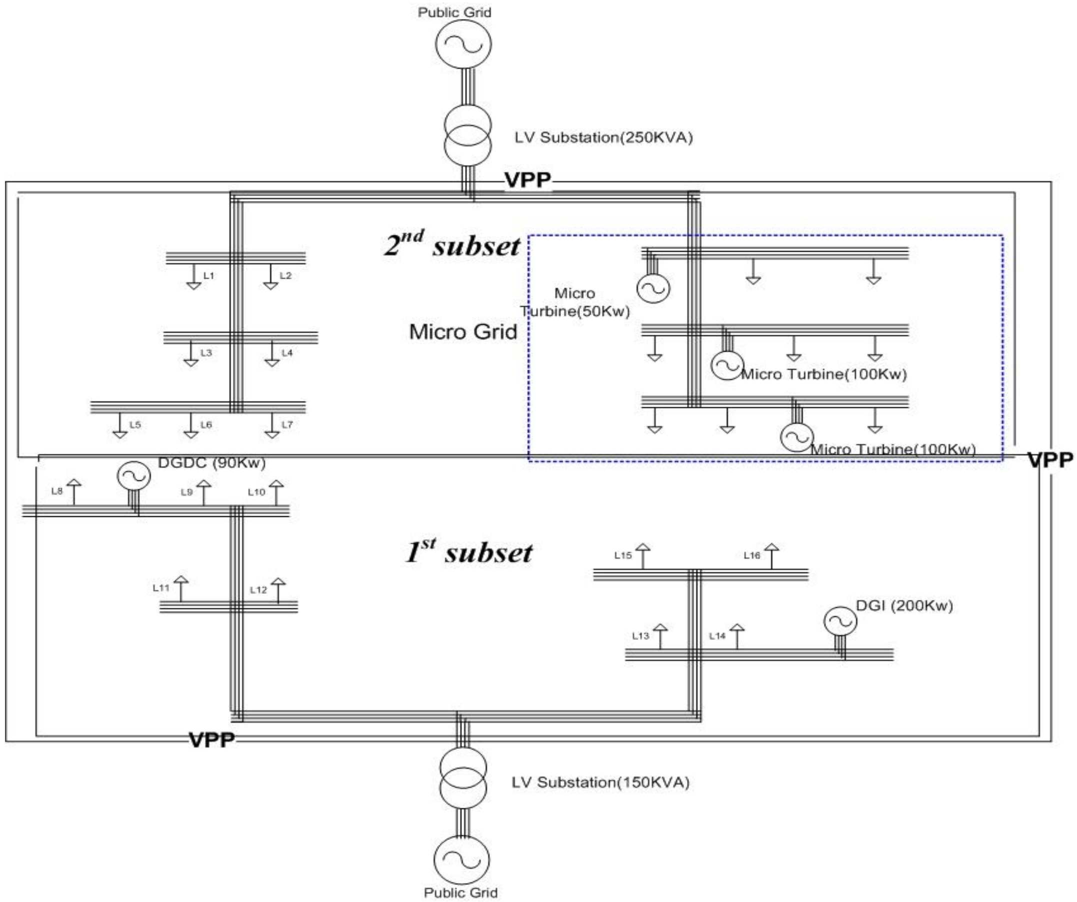

Figure A2. Structure distribution network which is located in VPP zone.