



Optimal Energy Dispatch Analysis Using the Inclusion of Virtual Power Plants Based on Dynamic Power Flows

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Abstract. The growing manifestation of non-conventional renewable energies, in modern electrical power systems, creates a great challenge on the normal operation of the system and planning the dispatch of active power, in economic terms. In order to achieve the objective of economic dispatch and be competitive in the electricity market, the concept of virtual power plant (VPP) has been introduced. It considers electrical elements and equipment with the aim of working as a single set that generates economic and operational benefits to the electrical system, taking into account the features and restrictions for an energy dispatch scenario. This paper proposes a case of study that considers the use of a virtual power plant in order to analyze the effects caused along the network. The optimal dynamic flow of AC power (ODFAC) uses a non-linear programming algorithm and how it is affected not only for the restrictions of the electrical elements and equipment but also for the restrictions of the topology and formation of the electrical power system. The IEEE 9-bar system is used to illustrate the efficiency of the method, comparing the results of the system with and without the integration of a virtual power plant.

Keywords: Economic dispatch · Energy management system (EMS) · Optimization · Planning · Power Flow · Renewable Energy Source (RES) · Virtual Power Plant (VPP)

1 Introduction

The study and research of non-conventional renewable generation technologies for a sustainable development with the environment, has started with the use of medium-scale of wind and photovoltaic generation into the electric power grid,

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with the aim of reducing the use of fossil fuels and decreasing levels of environmental pollution [1]. Including non-conventional renewable energy sources in electrical power systems (EPS) it is not an easy job, because it has to be considered a complete analysis of the reliability and quality of the energy delivered, due to the fact that renewable energy is not a constant source of energy. In addition, the variation over a cycle of time of both demand and generation restricts the inclusion of a virtual power plant to maintain stability levels that allow continuous operation of EPS. One of the solutions to maintain the continuous operation of a virtual power plant is to add a thermal generation plant or use energy storage by creating a micro-network in a specific space of the EPS, which allows supplying the demand without any interruptions [2].

The progress on the information and data transmission technologies fields for smart grids allow these concepts to be applied on a larger scale for the management and operation of a set of non-conventional renewable power plants, and also let than other electrical elements or equipment can be incorporated to the electric power system as a set called virtual power plant, which permits the use as a clean energies within the electricity market [3]. Managing and operating an EPS allows planning and dispatching of electrical energy in an efficient way. Thus, in order to archive this aim, a mathematical optimization method have been used, where the most known are: linear programming, gradient method, non-linear programming, dynamic programming, etc. [4].

The optimal power flow is fundamental in the electrical power systems analysis because it shows how electricity generation must supply the energy demand based on the restrictions of the EPS topology and the properties or sizes of the electrical elements and equipment [5–7]. If restrictions about both time and energy generation are also added to the elemental problem of optimal power flow, the problem becomes a dynamic scenario, called optimal dynamic power flow (ODPF) [9], creating a more complex problem, but the method in order to find a solution for it is essential to obtain results that represent real operating conditions in the power systems which is been analyzed [10]. The objective of this article is to present the behavior of the optimal dynamic power flow in power systems that have a virtual power plant with high participation of non-conventional renewable energies.

The application of these methods on the optimization process of a variable of the electrical system requires large amounts of computational memory and high processing times due to the large number of equations and variables that exists in the modeling of the electrical power system [11]. Therefore, current research are now focus in the implementation of meta heuristic or evolutionary algorithms (EA), also methods such as Strategic Evolution (SE), Genetic Programming (GP), Genetic Algorithms (GA) and Evolutionary Programming (EP) can be used as well [12].

In the second section of the article, the concept of virtual power plant is explained. Section three discourses the mathematical model for optimal power dispatch in an EPS which integrates a virtual power plant using dynamic power

flows. The four part integrates an analysis of the results obtained and finally, in the last section the conclusions of the current paper are showed.

2 Virtual Power Plant (VPP)

A virtual power plant is a set of elements that can be made up of conventional and non-conventional renewable generation sources (wind or solar), energy storage systems, controlled loads, communications system, management system (EMS) and system control, in order to carry out the economic energy dispatch on the electricity market compared to large conventional generation plants (hydroelectric, thermoelectric, gas) [13, 14].

A virtual power plant must ensure the delivery of the right amount of power, for this reason it can be included a hydroelectric or thermal generation plants depending on the minimum dispatch capacity of the virtual power plant, thus the penalty by the electricity market regulator entity will be avoided [15, 16]. Additionally, the inclusion of these conventional renewable energy sources allows the virtual power plant to have adaptability to face off stability problems that can occur in an electrical power system [17, 18]. It is important mentioning that [19] perform a complete analysis of the energy dispatch in a virtual power plant taking into account two stages. The first one considers the electricity market restrictions and the second one reflects the topology and characteristics of operation of both the EPS and virtual power plant. Furthermore, it has to be considered that priority is given to the dispatch of energy by a virtual power plant because it is made up of non-conventional renewable energy sources, despite the high costs it represents in the electricity market [20, 21].

In the model applied to a VPP it is important considered factors, such as energy producers, consumers and flexible consumers; because these ones have communication and control systems that allow shifting the electric power requirement to suitable periods of time for the operation of the VPP, without affecting the essential activities of the consumers or clients associated with this model. In [22, 23] the optimal operation point of a virtual power plant is analyzed based on two facts, the benefits for investors and the technical conditions of the electric power system.

2.1 Economic Dispatch

The schedule for an energy dispatch along EPS must be carried out in a reasonable way for a specific period or moment of time, considering possible demand scenarios, economic and technical criteria, ensuring a safe and reliable electrical system [24]. The main aim in the problem of economic dispatch is to reduce generation costs, considering restrictions of the EPS, such as system topology, maximum and minimum limits, electrical elements and equipment features. Optimal values are calculated for independent or control variables (Active and reactive power in PV node, transformer tap, etc.). According with the results obtained, there are values in the state variables (magnitude and angle of the voltage at

bars, reactive power generation, transmission line loads, etc.), thus the solution set of the optimization problem would indicate the stable and reliable operation of the EPS [25].

About the problem of economic dispatch, the literature classifies it into two segments; the first one is considered a static economic dispatch with a constant demand and defined restrictions. The second one defines the demand and some variable restrictions in certain periods of time, taking into account different types of operation, thus determining that minimum generation costs in both cases [26, 27]. In [28] the virtual power plant is considered as a conventional power plant and the economic dispatch is carried out using the linear programming method. In [1] the energy dispatch of a virtual power plant is showed within a Smart Grid. In [12] the energy dispatch is carried out considering the demand variation and restriction of energy resources.

The algorithm presented in this paper allows obtaining information about line chargeability, voltage magnitude and angle in bars, active and reactive power dispatch. It has been considered 24 scenarios in which the energy demand is variable, conventional restrictions for synchronous machines, adjustable maximum limits on the virtual power plant and a continuous lower limit considering the contract that a virtual power plant must fulfill within the electricity market. In addition, the analysis ensures the total demand supply and compliance of technical restrictions along the network.

3 Problem Statement

This document presents an analysis of the energy economic dispatch in time intervals. By adding time constraints and due to the dynamic behavior of non-conventional renewable energy sources; the optimal power flow is converted into an optimal dynamic power flow (ODPF). These considerations end into a more complex problem that involves both the time variable and the network restrictions; therefore, method used for the implementation of the system is essential to obtain a solution that represents reliable operating conditions of the electrical system.

In [29, 30] shows the measure of optimal dynamic stochastic power flow (DSOPF), in order to achieve an optimal power flows and consequently operate electrical energy networks that integrate non-conventional renewable energy sources.

The model selected to carry out the dispatch considers particular restrictions of the power electrical system, restrictions associated with elements and equipment, restrictions of maximum limits and minimum variables of non-conventional renewable electricity generation.

The optimal dispatch of energy allows obtaining active generation results that represent normal operating conditions for the EPS, depending on the availability of energy resource and the restrictions of the scenario, which is analyzed at that time, thus suppling the demand at a minimum cost [29, 30].

To solve the dynamic dispatch of generation using a virtual power plant, the renewable resource available from wind and solar energy has to be integrated

as a set in order to with the power system, where the conventional generators maintain their characteristics and restrictions [31,32].

3.1 Dynamic Optimal Dispatch Model Based on FOPAC

There are several solution models for economic dispatch, however for this solution method is based on the mathematical equations that represent the general AC power flow. Also is important to mention that an economic dispatch is developed in several periods of time considering the randomness and restrictions of the variables associated with the solution. The main component of the optimization problem is the objective function, which is displayed in Eq. (1):

$$OF = \sum_{i,t} b_g P_{i,t}^g + \sum_{i,t} B P_{i,t}^{sol+eol} \tag{1}$$

The objective function is subject to mathematical modeling of the AC power flow: power balance among generation, load and transmission (2) and (3), current flow along transmission elements (4), total power generated (5), active and reactive power at each node (6) and (7). All variables mentioned above are quantities that can change in order to balance the relation among generation, demand and losses [33].

$$P_{i,t}^g + P_{i,t}^{sol+eol} - P_{i,t}^L = \sum_{j \in \Omega_i^i} P_{ij,t} : \lambda_{i,t}^p \tag{2}$$

$$Q_{i,t}^g + Q_{i,t}^{sol+eol} - Q_{i,t}^L = \sum_{j \in \Omega_i^i} Q_{ij,t} : \lambda_{i,t}^q \tag{3}$$

$$I_{ij,t} = \frac{V_{i,t} \angle \delta_{i,t} - V_{j,t} \angle \delta_{j,t}}{Z_{ij} \angle \theta_{ij}} + \frac{b V_{i,t}}{2} \angle (\delta_{i,t} + \frac{\pi}{2}) \tag{4}$$

$$S_{ij,t} = (V_{i,t} \angle \delta_{i,t}) I_{ij,t}^* \tag{5}$$

$$P_{ij,t} = \frac{V_{i,t}^2}{Z_{ij}} \cos(\theta_{ij}) - \frac{V_{i,t} V_{j,t}}{Z_{ij}} \cos(\delta_{i,t} - \delta_{j,t} + \theta_{ij}) \tag{6}$$

$$Q_{ij,t} = \frac{V_{i,t}^2}{Z_{ij}} \sin(\theta_{ij}) - \frac{V_{i,t} V_{j,t}}{Z_{ij}} \sin(\delta_{i,t} - \delta_{j,t} + \theta_{ij}) - \frac{b V_{i,t}^2}{2} \tag{7}$$

In the equation presented below, it can be seen variables restrictions, such as: active power (8), reactive power (9) and maximum limit of active power transmitted end to end lines (10).

$$P_i^{g,min} \leq P_{i,t}^g \leq P_i^{g,max} \tag{8}$$

$$Q_i^{g,min} \leq Q_{i,t}^g \leq Q_i^{g,max} \tag{9}$$

$$P_{ij}^{\min} \leq P_{ij,t} \leq P_{ij}^{\max} \quad (10)$$

The Algorithm 1 shows the methodology used to carry out the economic dispatch in an electrical power system that includes a virtual power plant using dynamic power flows, based on nonlinear programming.

Algorithm 1. Economical energy dispatch based on dynamic power flows

Step: 1 Input data

Electrical elements and equipment parameters to build the network topology
 Z_{ij} , $P_{i,t}^L$, $Q_{i,t}^L$, $P_i^{g,max/min}$, $Q_i^{g,max/min}$, $P_{ij}^{g,max/min}$, b_g , B

Step: 2 VPP

$$VPP = \sum_{i,t} P_{i,t}^{sol+eol}$$

s.t.:

$$P_{i,t}^{sol+eol,min} \leq P_{i,t}^{VPP} \leq P_{i,t}^{sol+eol,max}$$

Step: 3 Economic dispatch

O.F.:

$$OF = \sum_{i,t} b_g P_{i,t}^g + \sum_{i,t} B P_{i,t}^{sol+eol}$$

s.t.:

$$P_{i,t}^g + P_{i,t}^{sol+eol} - P_{i,t}^L = \sum_{j \in \Omega_i^g} P_{ij,t} : \lambda_{i,t}^p$$

$$Q_{i,t}^g + Q_{i,t}^{sol+eol} - Q_{i,t}^L = \sum_{j \in \Omega_i^g} Q_{ij,t} : \lambda_{i,t}^q$$

$$I_{ij,t} = \frac{V_{i,t} \angle \delta_{i,t} - V_{j,t} \angle \delta_{j,t}}{Z_{ij} \angle \theta_{ij}} + \frac{b V_{i,t}}{2} \angle (\delta_{i,t} + \frac{\pi}{2})$$

$$S_{ij,t} = (V_{i,t} \angle \delta_{i,t}) I_{ij,t}^*$$

$$P_{ij,t} = \frac{V_{i,t}^2}{Z_{ij}} \cos(\theta_{ij}) - \frac{V_{i,t} V_{j,t}}{Z_{ij}} \cos(\delta_{i,t} - \delta_{j,t} + \theta_{ij})$$

$$Q_{ij,t} = \frac{V_{i,t}^2}{Z_{ij}} \sin(\theta_{ij}) - \frac{V_{i,t} V_{j,t}}{Z_{ij}} \sin(\delta_{i,t} - \delta_{j,t} + \theta_{ij}) - \frac{b V_{i,t}^2}{2}$$

$$P_{i,t}^{g,min} \leq P_{i,t}^g \leq P_{i,t}^{g,max}$$

$$Q_{i,t}^{g,min} \leq Q_{i,t}^g \leq Q_{i,t}^{g,max}$$

$$P_{ij}^{\min} \leq P_{ij,t} \leq P_{ij}^{\max}$$

Step: 4 Report optimization results by period

$$V_{i,t}, \delta_{i,t}, P_{i,t}^g, P_{ij}, Q_{i,t}^g, Q_{ij},$$

where,

OF	Objective Function
b_g	Generation cost coefficient of unit g
$P_{i,t}^g$	Available active power of the generator g on bus i at time t
B	Cost coefficient of the Virtual Power Plant
$P_{i,t}^{sol+eol}$	Active power available from VPP on bar i at time t
$P_{i,t}^L$	Variable active load on bar i at time t
$P_{ij,t}$	Active power flow on transmission line which connecting bus i with bus j at time t

$Q_{i,t}^g$	Generator reactive power g on bus i at time t
$Q_{i,t}^L$	Variable reactive load on bar i at time t
$Q_{ij,t}$	Active power flow on transmission line which connecting bus i with bus j at time t
$I_{ij,t}$	Current flow on the element that connects bar i with bar j at time t
$V_{i,t}$	Voltage magnitude across bar i at time t
$\delta_{i,t}$	Voltage angle across bar i at time t
Z_{ij}	Element impedance which connecting bar i with bar j
b	Branch susceptance which connecting the bar y with the bar j
$S_{ij,t}$	Apparent power on transmission element that connects bar i with bar j at time t
$P_i^{g,max/min}$	Maximum/minimum power generation limit of unit g at time t .

4 Analysis of Results

The algorithm was developed in the MATLAB software R2018b, which is linked with GAMS software often used for solving optimization models. MATLAB allows handling input parameters and data for modeling of problems; while GAMS executes the model solution, storing input data and optimization results. The simulations are developed on a computer with an Intel (R) Core (TM) i7-4700MQ CPU @ 2.40 GHz, 8 GB of RAM and Windows 8. NLP solver is used for each period in GAMS.

4.1 Study Case

In order to observe the behavior of the algorithm used to obtain the economical dispatch of energy in a EPS that integrates a virtual power plant; some simulations are carried out with the data corresponding to IEEE 9-bar electrical system considering the data in Table 1 and thus the dispatch results obtained are examined as valid operating conditions.

Table 1. Generators and VPP data

Gen.	Bar (i)	c[\$/MWh]	Pmax [MW]	Pmin [MW]
G1	1	11	200	5
G2	2	12	165	5
G3	3	10	85	5
VPP	5	9	20	0

Optimal dynamic power flows have been performed with and without the integration of the VPP in bar 5. The inclusion of VPP at bar 5 is used due to the fact that its voltages results in the AC optimal flow simulations produce the

minimum value compared to the other bars of the power system. The active and reactive power demand of the system is variable on the particular bars in the 24 periods analyzed. In addition, due to the availability of the non-conventional renewable energy resource is dynamic, the virtual power plant has different active power capacity to deliver to the EPS in each period.

Figure 1 shows the results of angle variation of each generator considering the scenarios already mentioned previously, taking into account the generator of bar 1 as oscillating.

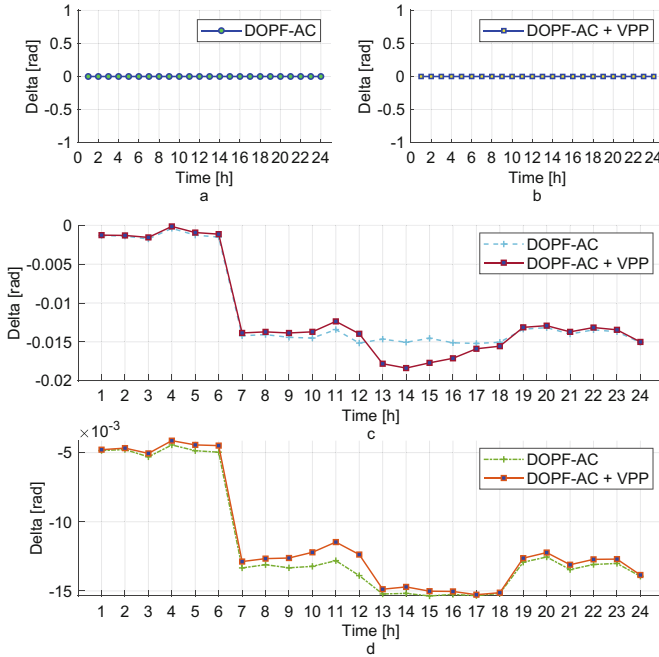


Fig. 1. Result of system angles. (a) and (b) Bar 1, (c) Bar 2, (d) Bar 3

According with the data obtained, it is evident that its value remain without any changes; however, the angles corresponding to the remaining synchronous machines decrease their value in each active power dispatch period for the interval between 7:00 and 18:00. For this case, the virtual power plant delivers the maximum amount of active power available, due to the stochastic nature of non-conventional renewable energy sources.

Also, some changes are detected at the bus associated with generator 2, which has the highest generation cost, mainly because at the interval in which the VPP delivers less power to the electrical system, there is variation in the value of the angle in generator 3, despite that it always delivers 85 MW in both cases. This result is due to the fact that state variables, such as the angles at the bars, not

only depend on the generation at bar 3, since this result is associated with all the variables and equations that conform the mathematical method in the model of the electric power system.

Figure 2 shows the results of voltages at the bars of the IEEE 9 bar electrical system. It presents a simulation of the inclusion of a virtual power plant at bar 5 because the resulting voltage values at this bar, in comparison with the others ones, were the minimums values obtained along the electrical system, and thus improve the value of the voltage for each period.

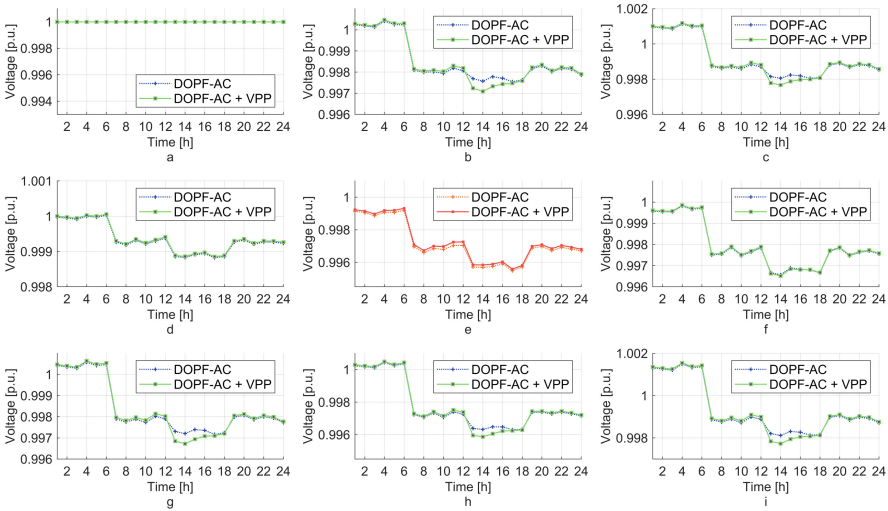


Fig. 2. Voltage results. (a) Node 1, (b) Node 2, (c) Node 3, (d) Node 4, (e) Node 5, (f) Node 6, (g) Node 7, (h) Node 8, (i) Node 9

As it was expected, bar 1 related with the slack generator maintains its value at 1 p.u. for each period analyzed in both scenarios. For the analysis of the remaining results, it will be developed in pairs since the bars are associated with a power transformer in each generation machine. At bars 3 and 9, a decrease in the voltage values is detected in the period between 1:00 p.m. and 4:00 p.m. For this specific case, the virtual power plant delivers the greatest amount of active generation power; therefore, the power transfer is modified in the transmission system, which changes the results obtained.

A similar situation exist at bars 2 and 7. In bar 4 there are no variations because it is connected to the transformer of the oscillating machine. In bars 6 and 8 that are associated with the EPS loads, the inclusion of VPP affects the bar that is feeding the highest load in the period analyzed. In bar 5, for each period analyzed, the voltage levels improve lightly despite the fact that this bar is connected with the highest load in the system.

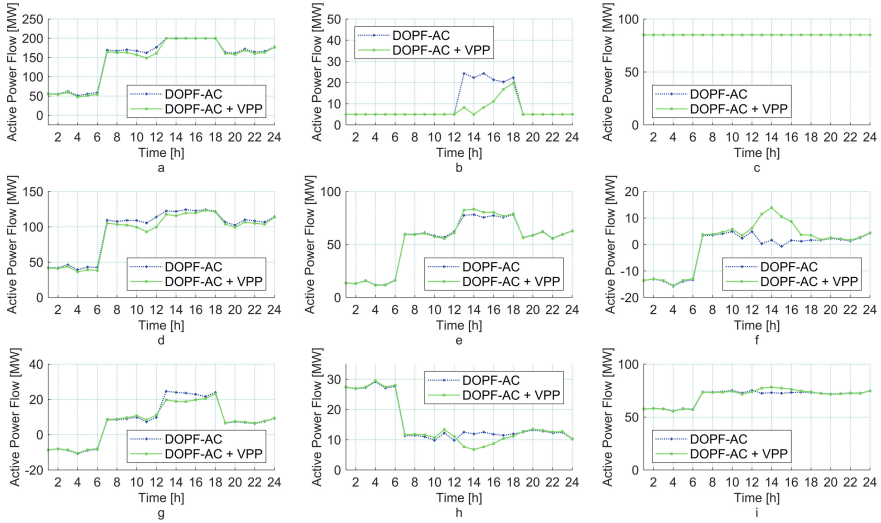


Fig. 3. Result of active power transfer along transmission lines and power transformers. (a) Trf 1-4, (b) Trf 2-7, (c) Trf 3-9, (d) LT 4-5, (e) LT 4-6, (f) LT 5-7, (g) LT 7-8, (h) LT 9-6, (i) LT 9-8

Figure 3 analyze the results of the active power with transmission elements and power transformers. The transformer associated with generator 1 has an average generation cost and its maximum and minimum power limits are adequate; also, it delivers most of the required active power to the system. For the interval between 8:00 a.m. and 12:00 p.m., due to the conditions and restrictions of the problems, it stops to deliver, to the electricity system, a minimum little quantity of active generation, approximately between 1 to 3 MW in each period.

For the transformer associated with generator 2, which has the highest generation cost, the active power flow through this electrical element, in most of the periods, is at a value of 5 MW; mainly, because this is the minimum restriction of active power associated with generator 2. In the period between 12:00 and 18:00, in which the load increases, this generator delivers the greater amount of active power to meet demand. In this same period with the inclusion of the virtual power plant, the transformer 2-7 transmits less power since the VPP assumes the increasing demand in the electrical power system due to its low production cost.

For the transformer associated with generator 3, the active power values transferred by this element do not change because the generation cost is the lowest after the generation cost of the VPP and it satisfies the solution for power flows. The results related with transmission lines 4-5, 5-7 and 7-8, have a greater influence over the income of the virtual power plant. For this scenario, the transfer of active power increases or decreases due to these elements; thus,

the transmission line 5–7 is the one that has remarkable changes due to the fact that it is associated with the greater load of the electrical power system.

Likewise, for the remaining elements such as: transmission lines 4–6, 6–9 and 9–8, there are negligible changes in the active power flow, for a time interval between 12h00 to 16h00. This is a consequence that the additional generation source generates 19 MW, which is mostly consumed in bus 5; the rest of the active power is distributed to the electrical power system through different transmission lines to supply the load and at the same time satisfy the equations using for the mathematical model of AC power flow.

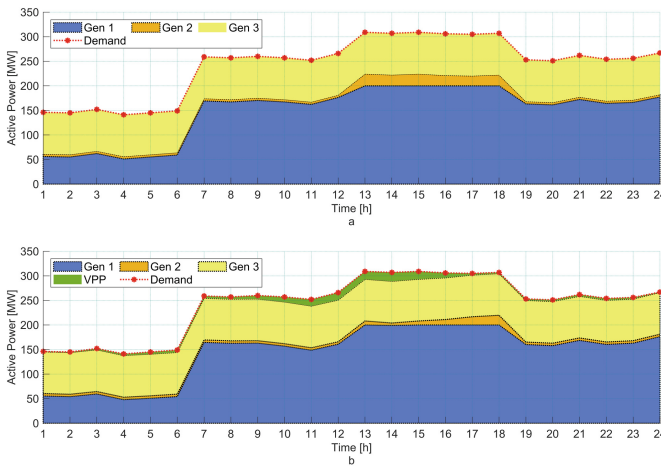


Fig. 4. Active Power Dispatch; (a) without PPV (b) with PPV

Figure 4 shows the effect of active power dispatch in generators with and without the integration of the virtual power plant. In both scenarios, the generation supplies the demand of the electric power system; consequently, the algorithm fulfills the objective of delivering results that represent effective operating conditions. Most of the active generation delivered by the virtual power plant is located between 9:00 a.m. and 5:00 p.m.; in the opposite hand, in the remaining periods the VPP delivers its minimum generation capacity restricted by the random and stochastic conditions of the non-conventional renewable energy sources used, such as solar and wind energy.

Keeping generation costs constant for a scenario without using a virtual power plant, there is a minimum value of demand for active power of 141 MW at 4h00; in which machine 2, with the maximum generation cost, delivers to the system only 5 MW which is the lower generation limit. Generator 3, with the lowest generation cost, delivers its maximum power of 85 MW due to the restriction values; meanwhile, machine 3 delivers the remaining power value to meet the supply of demand which is 51.1217 MW. Additionally the losses of the

electrical power system, therefore the total active power that must be supplied in the IEEE 9 bus system for this case is 141.1217 MW.

According with previous consideration, the results achieved with the inclusion of VPP, in the period of 4:00 am are as follows. First, the values specified in machines 2 and 3 are preserved without the integration of VPP, because its minimum and maximum generation restrictions and the generation cost, both remain constant results. Second, the remaining load to feed the system would be 51 MW plus losses associated with this power dispatch schedule, for this the virtual power plant assumes approximately 3.2 MW, which is the maximum of its capacity at that moment, thus machine 1 dispatches 47.9197 MW to supply the total demand plus the associated losses.

Regarding with the information presented above, it is evident that the generation of active power in machine 1 changes, thus adapting itself to the insertion of the VPP. Additionally, the losses reduce along EPS, and exist a higher value of the total cost of generation without the integration of the VPP which is \$ 1472.3, while the cost with VPP is \$ 1465.9; therefore, there is a saving of \$ 6 approximately.

At 2:00 p.m. is the time in which the VPP delivers its highest active power capacity to the system and there is a high demand for electrical energy. For this scenario without considering a VPP, the data is the same of Table 1. The cheapest machine is 3, so it delivers its maximum active power equal to 85 MW to the electrical system according to its maximum limits. Machine 2, according to its generation costs and its maximum generation power, it delivers 200 MW to the system. Therefore, generator 3 supplies to EPS the necessary active power in order to cover the remaining demand and losses; despite its high generation cost, it delivers 22,3115 MW.

For the analysis with the integration of the virtual generation plant exist equal conditions in the restrictions of elements and equipment as the previous scenario, so generator 3 is cheaper after the VPP, and it continues to deliver its maximum capacity to the system electricity, which is 85 MW. Due to the fact that generator 2 has the highest cost, now it delivers its minimum power, which is 5 MW. Finally, generator 1 delivers an active power of 199.0229 MW to the electrical system, while the VPP now assumes the remaining power to supply the demand including the losses associated with the active power dispatch schedule.

According with the previous results, it can be seen that only the active power generation, in machine 1, changes adapting according to the contribution of the VPP. Additionally, despite the fact that the losses increase, they are not relevant compared to the dispatch values that exist in the machines. There is a highest value of the total generation cost without the integration of the VPP which is \$ 3317.7, while the cost with VPP is \$ 3264, therefore there is an approximate saving of \$ 53.7. The active power losses differ by 0.0114 MW, mainly because the current flow along ESP is not the same since generators have different active power values.

5 Conclusions

The results achieved show the efficiency and strength of the proposed methodology. It may allow the operator of a EPS to plan the dispatch of energy considering the use of non-conventional renewable energies in certain periods of the day, taking into account the structure and features of the EPS, allowing the reliable operation of EPS in scenarios of maximum or minimum demand.

The economic dispatch of energy using an optimal dynamic power flow considering the insertion of non-conventional renewable energies (wind and solar) based on the proposed methodology, allows the evaluation of results and restrictions that contribute in the formulation and solution of this problem. This provides a clear idea of the behavior of the active generation power compared with some simulation scenarios that reproduces the uncertain presence of the energy sources considered. All this process guarantees an economic dispatch that represents an operational and economical solution for the power electrical system.

The set of electrical elements and equipment known as virtual power plant (VPP), has the capability to join to the speculative and dynamic essence of non-conventional renewable energy sources. Due to the variability of energy demand and supply, the virtual power plant should be considered as a secondary type of generator, in the planning of the dispatch of active power. Thus, VPP can be integrated to participate in the electricity market in a competitive and efficient way depending on the requirements and conditions that requires EPS in a certain period of the day or throughout the day.

The proposed methodology shows a consistent and powerful behavior when considering several simulation scenarios with different demands and energy availability. This allows obtaining and analyzing results the whole day, noticing that do not exists convergence problems in the solution and the results are according with established ranges of normal operation of an EPS. Therefore, from technical point of view, it can assistance to the operator to find a perfect balance between demand and generation, especially in periods when the use of the virtual power plant is required.

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