Optimal Dispatch of Renewable Sources Under Virtual Power Plant

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Abstract The main grid integrated into renewable energy source can be challenging due to their intermittent and unpredictable nature. However, incorporating battery energy storage systems (BESS) into renewable energy systems can provide several benefits. To fully exploit the advantages of BESS, an optimal energy management strategy is required. The Concept of a Virtual Power Plant (VPP) can combine the strength of renewable energy sources and simplify management for a decentralized energy market. The proposal introduces a new structure for optimal energy management of a Virtual Power Plant. The framework considers important aspects, such as managing the risk associated with renewable energy sources, reducing operating costs, and managing voltage levels within the system. Additionally a stochastic simulation with two stages is created to address the issue of unpredictable Power bills and RES generation. The simulation results indicate that the proposed framework can enhance the system by ensuring energy balance accuracy, reducing energy and maintaining system security. By incorporating the VPP approach and optimal energy management strategies, the integration of renewable energy sources and BESS can be streamlined and made more effective.

Keywords Distributed generations · Battery energy storage system · Optimal energy management · Virtual power plant · Renewable energy system · Stochastic method · Deterministic method

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1 Introduction

Environmental concerns have led to a rise in the use of renewable energy sources (RESs), such as solar, wind power, bio-gas, etc., along with rising demand for energy and a decreasing distribution of fossil fuels with high carbon content. Many Countries have created laws regarding RES as well as standards to encourage the use of RES [1], and as a result, there is a large growth in other sectors of power systems, including renewable Distributed Generators [2]. However, because RES is unpredictable and variable, managing and controlling it in a typical electricity system is challenging [3]. It has been noticed that integrating RESs and various other traditional distributed generators and BESS like thermal plants, micro-CHP, etc. can significantly address the balancing of power and regulating voltage fluctuations [4].

(BESS) have a significant role in modern power systems, as they can directly address the renewable energy intermittency, provide technical support for power systems, and develop smart grid technology [5]. BESS have been researched in a wide range of renewable energy systems to improve the integration of renewable energy, from small-scale systems like distributed renewable systems and micro-grids to large-scale freestanding hybrid renewable energy systems and renewable energy power plants [4, 6]. The reduction of transmission network congestion, assistance with voltage and frequency management, and the postponement of transmission network renovations and expansions are other significant applications of battery storage in power systems that require attention [7].

As mentioned in, VPP has two variants, referred to as commercial Virtual Power Plant (cVPP) and technical Virtual Power Plant (tVPP) [8]. A tVPP is made up of a few renewable DGs in the same geographic area and considers the actual impact of the local network on the whole portfolio. A commercial Virtual Power Plant works as a market operator and maximizes its profit without taking the conditions of the network into consideration [9]. VPP energy management differs from that of traditional power systems, which depends on the type, the level of penetration of RES, and the strategy for market participation. Many things have been done to solve the problem of how to manage VPP energy [10]. RES and BESS are two parameters taken into account by the electrical energy management employed for Virtual Power Plants. They proposed a theoretical energy management methodology for Virtual Power Plants with storage systems [11] and thermal and electrical generators, and introduced a regulation strategy for micro-CHP and wind that decreases operating price [12, 13]. But none of the above works have taken wind power and ESSs into account in a precise manner for tVPP energy management [14].

This paper presents an optimal Virtual Power Plant energy management issue model with wind energy systems, theoretical energy storage systems, and DGs inside the coming day and balancing business. The aim of the prototype is to maintain the energy balance of the Virtual Power Plant and system security while minimizing operational costs for the VPP, including those associated with operation, maintenance, and power market charges. To acknowledge the uncertainty in wind power gains and electricity pricing, a two-stage theoretical technique is presented.

The following are the paper's main contributions:

- A cutting-edge VPP energy management model that takes into account a number of crucial elements, such as the operation of dispersed wind and traditional generators, the higher perception of wind energy, and voltage regulation assurances of power quality.
- A double-mode stochastic optimization model to take into account different VPP uncertainty.
- Depending on earlier records of data sets proper simulations are presented, and the outcome demonstrates that the speculative strategy performs significantly more in lowering operating costs while preserving system dependability.

2 System Modelling

2.1 Virtual Power Plant Model

The suggested model concludes that the Virtual Power Plant is made up of Energy Storage Systems units, wind energy systems (Wind Turbines), micro-CHP units, and stable loads. Wind turbines reduce carbon emissions while the entire efficiency is produced by micro-CHP units [15]. Wind power outcome uncertainty is decreased with the coordination of battery storage and micro Combined Heat and Power(micro-CHP) [16]. When the actual generation of wind differs from that of the predicted total, batteries help to compensate for the imbalance by charging or discharging [17]. The Virtual Power Plant is assumed to be run by a central system, from which the holder receives predicted details and has direct authority over each subsystem. The system operating cost can be made low with the help of the controller. A distribution line connects the VPP units that are kept together which are linked to the major grid. The operational time is denoted by t divided by T time slots [18].

2.2 Model for Energy/Electricity Market

The Virtual Power Plant configuration is suggested to compete in the energy market in a manner same to the Nordic Energy Market [19], which is an aggressive double-settlement energy market comprised of an actual balancing market. Based on the operational restriction and evaluation of the entire profile, the top authority put their proposal for consumption or generation to the future market [20]. The actual energy/power transfer may differ from the power schedule due to uncertainty. To maintain power balance, the central controller must regulate the absolute-time power/energy transfer. Furthermore, if an unbalancing problem arises, an ascending or descending rule penance will be submitted in the balancing market [21].

3 Problem Interpretation

The issue is expressed as a stochastic prototype that has two stages. Energy Proposal and Unit commitment status of DG units in the future market are among the first-step opinion variables. The second stage consists of DG unit active and reactive power outcome, battery charge cycle, flexible load management, and absolute-time energy transfer in the electricity market.

3.1 Governing Function

$$min\sum\nolimits_{i}\sum\nolimits_{t}(\alpha_i p_{i,t}+\beta_i) \tag{1}$$

$$\sum\nolimits_{t}\left[p_t^{DA}\lambda_t^{DA}+\left(p_t^{BL}-p_t^{DA}\right)\lambda_t^{BL}-\phi_t\left|p_t^{BL}-p_t^{DA}\right|\right] \tag{2}$$

$$\sum\nolimits_{k}\sum\nolimits_{t}C_k\left(\frac{e_{k,t}^{-}}{\eta_k^{-}}+e_{k,t}^{+}\eta_k^{+}\right) \tag{3}$$

Equation (1) represents the operational cost of a virtual power plant, where $\alpha_i p_{i,t}$ denote the micro-CHP unit generation cost i for t time and the unit β_i is cost for no-load. When unit i is turned on, the zero-load cost is incurred.

Equation (2) mentions the VPP's market cost. In a two-settlement market, the hourly bid and real-time power exchange are denoted by P_t^{DA} and P_t^{BL}, respectively. When P_t^{DA} is negative or positive, the Virtual Power Plant has purchasing/selling energy in the future/coming market at a cost of λ_t^{BL}. The Virtual Power Plant is purchasing/selling energy/power on cost λ_t^{BL} in a balancing market when $P_t^{BL}-P_t^{DA}$) is negative/positive. The higher or lower regulation is given by $\phi_t\left|P_t^{BL}-P_t^{DA}\right|$, whenever the real-time power exchange and day-ahead power schedule are not equal then regulation ϕ_t is paid.

Equation (3) shows the price of battery storage k, where $e_{k,t}^{+}$ is rate of charging having efficiency η_k^{+} and $e_{k,t}^{-}$ is the rate of discharging having efficiency η_k^{-}.

3.2 Constraints

(1) *Equations of Power Flow*: swing bus is present at Bus 1 and linked to the major grid. The reactive power injection and active power injection are given in Eqs. (4) and (5):

$$P_{j,t}=\sum\nolimits_{i}P_{i,t}-p_t^{BL}-p_{j,t}^{LD}+\sum\nolimits_{n}w_{n,t}+\sum\nolimits_{k}\left(e_{k,t}^{-}-e_{k,t}^{+}\right),\forall t \tag{4}$$

$$Q_{j,t} = \sum_{i} q_{i,t} - q_t^{BL} - q_{j,t}^{LD}, \forall t \tag{5}$$

The difference between load consumption and the active power generation is known as net active power injection $P_{j,t}$. $P_{j,t}^{LD}$ denotes the consumption of the load active power on bus j, and $W_{n,t}$ represents the output of wind power for unit n. Similarly, the difference between consumption of load reactive power and generation of load reactive power is known as net reactive power injection $Q_{j,t}$. The equations of linear power flow are given by:

$$P_{j,t} = (2V_{j,t} - 1)G_{j,j} + \sum_{o(o \neq j)} G_{j,o}(V_{j,t} + V_{o,t} - 1) + B_{j,o}(\theta_{j,t} - \theta_{o,t}), \forall t \tag{6}$$

$$Q_{j,t} = -(2V_{j,t} - 1)B_{j,j} + \sum_{o(o \neq j)} - B_{j,o}(V_{j,t} + V_{o,t} - 1) + G_{j,o}(\theta_{j,t} - \theta_{o,t}), \forall t \tag{7}$$

$$P_{j,o}^t = G_{j,o}(V_{j,t} - V_{o,t}) + B_{j,o}(\theta_{j,t} - \theta_{o,t}), \forall t \tag{8}$$

$$Q_{j,o}^t = B_{j,o}(V_{o,t} - V_{j,t}) + G_{j,o}(\theta_{j,t} - \theta_{o,t}), \forall t \tag{9}$$

where $P_{j,o}^t$ is the active power flow over branch (j,o) and $Q_{j,o}^t$ is the reactive power flow over branch (j,o). $V_{j,t}$ denotes the magnitude of voltage and $\theta_{j,t}$ denotes the phase angle at bus j. $G_{j,o}$ is real parts of the Virtual Power Plant admittance matrix at branch (j,o) and $B_{j,o}$ is the imaginary parts of the Virtual Power Plant admittance matrix at branch (j,o).

(2) *Constraints in Network*. To secure the system, the network congestion as. well as phase angle and magnitude of voltages at each bus are needed to be in a secure operational period. Therefore, Eq. (10) defines an upper and lower limit for voltage whereas Eq. (11) represents the power flow over branches.

$$V_j^- \leq V_{j,t} \leq V_j^+, \theta_j^- \leq \theta_{j,t} \leq \theta_j^+, \forall j, \forall t \tag{10}$$

$$P_j^- \leq P_{j,o}^t \leq P_j^+ Q_j^- \leq Q_{j,o}^t \leq Q_j^+, \forall j, \forall t \tag{11}$$

(3) *Constraints in Battery Storage.* Since battery power lies in a specified range, a higher and lower limit for batteries' size $E_{k,t}$ is governed by following two equations respectively to avoid the rate of over-charging or over-discharging.

$$E_k^- \leq E_{k,t} \leq E_k^+, \forall k, \forall t \tag{12}$$

$$E_{k,t+1} = E_{k,t} + \left(\frac{e_{k,t}^-}{\eta_k^-} + e_{k,t}^+ \eta_k^+ \right), \forall k, \forall t \tag{13}$$

4 Test Analysis

4.1 Data

The proposed Virtual Power Plant model (Fig. 1) is based on a modified IEEE 13-bus distribution test feeder [11]. Buses 6, 7, and 11 have three micro-CHP units, On bus 9, there is one wind turbine, and on buses 2 and 10, respectively, there are two battery storage systems. In the actual test feeder, the transformer and switch are replaced by distribution lines [7]. The base values voltage magnitude is to be set at 4.16 kV and apparent power base values are to be set at 5000 kVA. The VPP central control is assumed to be able to receive the information to be forecasted and to have straight control over entire unit. The micro-CHP units parameters are displayed in Table 1, while Table 2 displays data from the battery storage system. Historical details are collected to address the power demand, market prices and the wind power, and to meet the required install capacity demand, these data are scaled down.

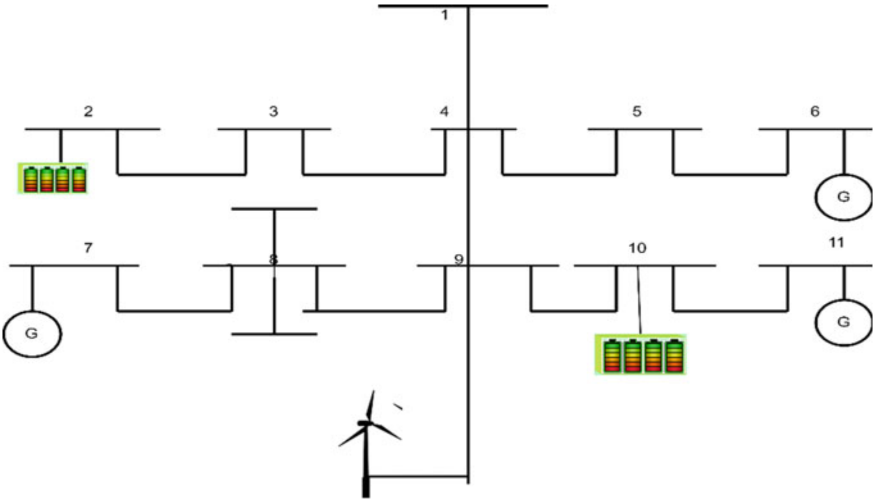

Fig. 1 IEEE 13—bus distribution test feeder

Table 1 Parameters for micro-CHP units

Unit	α_i($/kWh)	β_i($)	P_{cap}(kW)
1	0.15	30	1500
2	0.30	50	1000
3	0.50	70	1500

Table 2 Parameters for storage

E_k^- (kWh)	E_k^+ (kWh)
50	Max = 100
$e_{k,t}^-(kW)$	$e_{k,t}^+(kW)$
100	100

4.2 Result

(1) *Deterministic vs. Stochastic*:- The suggested deterministic strategy and a stochastic strategy to determine the Virtual Power Plant power management problem are firstly compared. Simulation result of proposed model can observed in Fig. 2. The figure shows the comparison between the stochastic and deterministic approaches for the 25 iterations. It is noted that growing wind penetration level benefits both approaches by lowering system operating costs. This happens as wind turbines are expected to have lower generation costs. Furthermore, the results show that the stochastic strategy performs better than the deterministic strategy, implying that the stochastic operation is more capable of dealing with RES uncertainties.

(2) *Voltage Control*:- To measure the power quality, voltage regulation one of component and in the use of RES, power quality is one of the concern. The higher and lower limits of phase angle are set to be 0.03 rad and the higher and lower limits for magnitude of voltage are set to be 0.5 p.u., in this case, and penetration of wind is set to be 20%. Both magnitude of voltage and phase angle are in the safe operating range as shown in Figs. 3 and 4 of the simulation results.

(3) *Associated with storage:-* Effectiveness of ESS in relieving ambiguity is assessed here. The use of battery storage systems and those without storages is

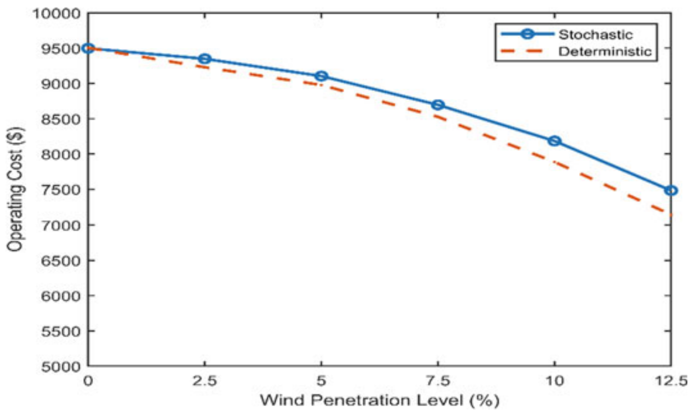

Fig. 2 Stochastic versus deterministic approach operating cost having different wind penetration

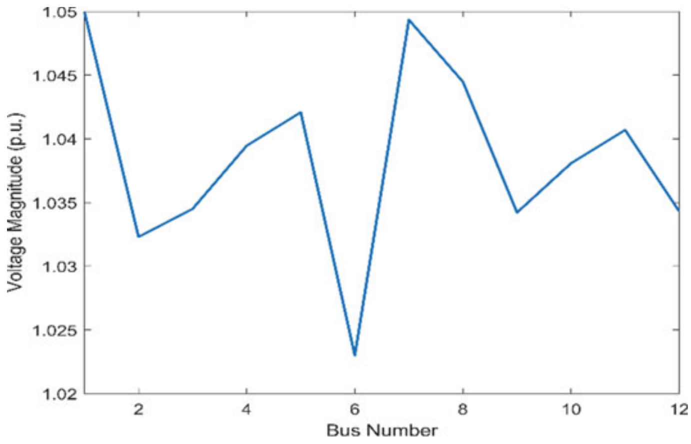

Fig. 3 Each bus voltage magnitude

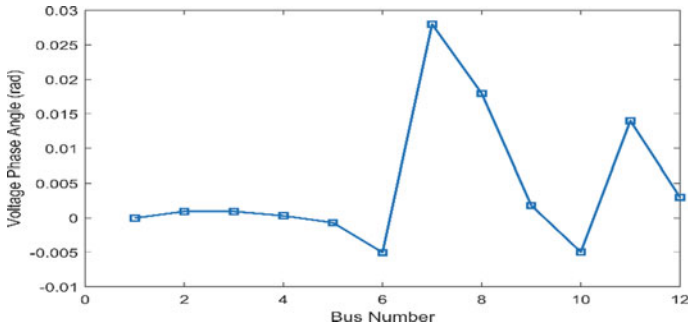

Fig. 4 Each bus voltage Phase

compared, and per day storage capital cost is included to the storage system. The storage of energy efficiency is set at 75%, and the wind penetration is set at 20%. Figures 5 and 6 show the simulation result. Figure 5 illustrates the effectiveness of storages in reducing power imbalance by showing that the system running cost is lower with ESSs added to the VPP than it would be without them. Additionally, Fig. 6 shows that the storage system's most efficient capacity is 200 kWh when the per capital cost of storage is included. Therefore, building storage capacity exceeding 200 kilo-Watt hour is not financially viable because the cost of the storage will exceed the revenue.

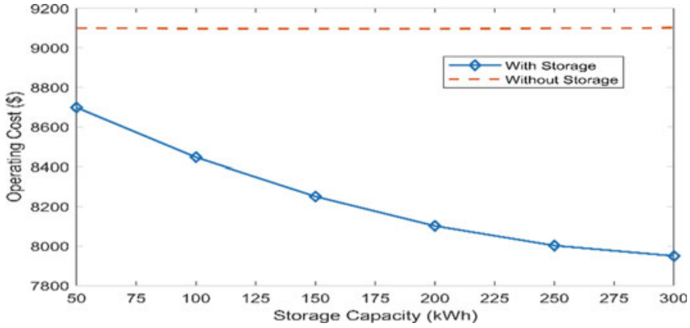

Fig. 5 Cost versus storage

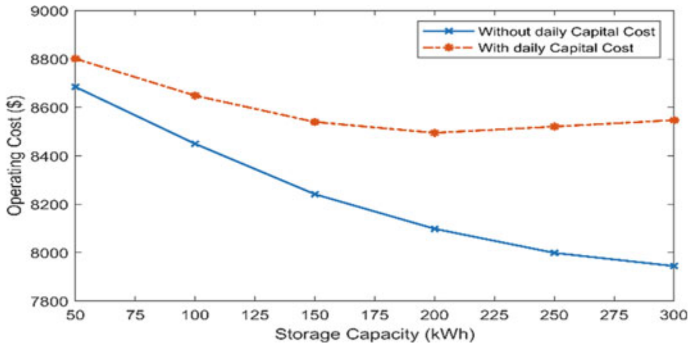

Fig. 6 Cost versus storage

5 Conclusions

This research provides an innovative energy management paradigm for VPP that includes energy storage and renewable power generation. The issue with A two-stage stochastic optimization problem is used to describe the task of minimizing the operational costs of the VPP in electricity markets. Numerous simulations have been run, and the results demonstrate how the framework can save operating costs for the VPP while managing power quality and security of system. Further scope of this work includes taking into account bidding technique in stochastic optimization and also expanding the quantity of input cases to evaluate results' stability and tackle many subtasks concurrently.

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