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Demand Response Management in Day Ahead Market for Optimal Energy Trading in VPP Framework using PSO

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***Abstract*—A Virtual Power Plant (VPP) aggregates a variety of distributed generation units as a single entity to participate in energy market. A VPP is very effective in utilizing the characteristics of distributed energy sources and implementation of demand response. This paper addresses energy trading and demand response scenario involving VPP, having PhotoVoltaic (PV) generation, along with primary and secondary electricity consumers. The participants engage in day ahead energy markets. In this paper, a novel demand response approach based on creation of two types of time zones namely excessive zone and non-excessive zone is proposed. The load scheduling is performed by shifting load in between these zones. A Particle Swarm Optimization (PSO) based technique is proposed between the VPP and users, to optimize the economic advantages of all participants. The results show that the proposed scheme improves the profit of VPP and simultaneously reduces the energy costs of users in day ahead energy market.**

***Index Terms*—Virtual Power Plant (VPP), Day Ahead Market, Demand Response, Energy Trading, PSO, Renewable Energy**

I. Introduction

To encourage both economic and environmental efficiency, the whole world is shifting towards Distributed Generation (DG). The use of wind power, PV and other forms of renewable energy sources (RES) is considered as an alternative to conventional power generation [1]. Also, RES can be utilized for participating in electricity market and provide ancillary services to system operators [2]. The RES are influenced by time and show variability and intermittency characteristics. This poses a big challenge on power system to operate in stable and reliable manner. For reliable operation and effective management of system, flexible units like Energy Storage Systems (ESS) and Demand Response (DR) are combined along with DGs.

Intelligent smart grids are designed to provide better resource management, grid security and stability, interactions between grid and consumers [3]. They may implement the idea of Virtual Power Plant (VPP) to be more effective. According to the European project FENIX [4], "VPP aggregates the capacity of many diverse Distributed Energy Resources (DER); it creates a single operating profile from a composite of the parameters characterizing each DER and can incorporate the impact of the network on aggregated DER output." VPP's are classified into two types, one is Commercial VPP (CVPP) and other is Technical VPP (TVPP). The CVPP addresses the aggregation of small generating units in terms of market integration and TVPP examines aggregation of these units in terms of services that can be provided to the grid. CVPP does not consider the impact of distribution network in its aggregated profile. In contrast, TVPP takes into account the real time influence of the local network on the DER aggregated profile. Individual small plants cannot compete in electricity market because they do not meet minimum bid size of market. Incorporation of RES into the existing market is another primary objective of a VPP.

DR is considered as an optimal way to provide flexibility to power systems [5]. DR is implemented to manage system load balance, gain benefits from peak shaving, enhance RES efficiency with faster response and low cost. Domestic loads are highly variable and widely spread compared to commercial loads. More individual consumers are getting involved along with the growth of smart grid. The individual consumers are more sensitive towards competitive prices rather than fixed contracts [6]. In VPP framework, VPP is responsible for setting rules, selecting and prioritizing DR programs. Customers modify their demand pattern to minimize the electricity costs.

In [7], a three stage program based on scenario approach is proposed for energy bidding formulation of VPP. To minimize the energy imbalance cost of VPP and maximize its profits, DR exchange market is exploited. The uncertainties in RES, retail customers demand and electricity prices are also considered. In Day Ahead Market (DAM), the VPP is responsible for energy balance and DR to minimize its energy imbalance cost. In [8], energy dispatch in VPP is performed by implementing DR based on Time Of Use (TOU) pricing. A multiVPP interactive dispatch is performed using infinitely repeated approach of game theory. The uncertainties of RES are considered. In [9], a novel DR method to minimize cost and maximize the utility of customers is proposed. For this, the load profiles of consumers are considered based on priority. A centralized management approach is utilized for managing the loads.

Also, the billing is performed after distribution of profits depending upon the selected load profile, fixed prices and overall profit. A three stage bi-level approach for optimal bidding strategy of CVPP in DAM and to minimize the energy imbalance costs is proposed [10]. The upper level of the problem deals with the profit maximization of VPP and lower level problem with market clearing problem for Independent System Operator (ISO). Conditional Value-at-Risk (CVaR) metric is incorporated to decide amount of risk level to be considered. Artificial Neural Network (ANN) based scenario generation is utilized for wind generation, Heating, Ventilation and Air Conditioner (HVAC) consumption and required loads. The bi-level optimization problem is modified to a Mixed Integer Linear Programming (MILP) problem using Karush-Kuhn-Tucker conditions and duality conditions. To maximize the profits of VPP bidding of energy and reserve capacities is proposed in day ahead and real time markets [11]. For this, a two level game methodology is proposed. In the lower level, using MILP the prices, schedule and quantity, reserve capacity and regulating reserve are determined in VPP. In upper level, using Cooperative game approach the market operator determines the market clearing price.

Market players submit there bids in DAM for the coming day before the gate closure. The participants are responsible for any power deviations after commitment. Any deviations will be settled in real time market via the regulation price. If there is any excess or shortage of energy production it is traded in real time market at lower or higher prices respectively [12].

In this paper, production is fixed, load is of flexible nature and total power transactions occurs in DAM. This paper deals with coordinated operation between the distributed energy and flexible load under VPP. The objective is to increase VPP profit and reduce users cost of buying electricity. In order to meet the interest of all participants the problem is modeled as an optimization problem between VPP and users. Particle Swarm Optimization (PSO) is utilized for solving the problem.

The paper is organized in the following sections, section 2, discusses PSO in brief. In section 3, the problem formulation is explained. Results for profit maximization and cost minimization for users is discussed in section 4. In section 5, conclusions have been derived.

II. Particle Swarm Optimization (PSO)

The decision making problem of DR leads to non linear optimization problem having multiple dimensions. This paper proposes a Particle Swarm Optimization (PSO) based methodology to solve this bi-level problem. A PSO algorithm is constructed involving VPP and load users to optimize the power selling strategy of VPP in power market while ensuring that the users interest is also not ignored during optimization process [13].

PSO is a population based stochastic optimization technique, motivated by bird flocking or fish schooling social behaviour [14]. The optimization technique depends on swarm movement and intellect. Each solution is considered as a bird, that traverses through the search space and is called as particle. Each particle is associated with a velocity with which it flies through the search space. The path of each particle in search space depends on its own flying experience and flying experience of current optimum particles [15]. Fitness value for all particles are to be optimized using the fitness function.

Each particle moves towards its personal best (PB) and global best (GB) associated by random weights. Velocity and position of particle is updated as shown in Eq 1 and Eq 2.

$$v_{i+1} = \omega * v_i + c_1 * rand() * (PB_i - x_i) + c_2 * Rand() * (GB_i - x_i) \tag{1}$$

$$x_{i+1} = x_i + v_{i+1} \tag{2}$$

where, v_i is the particle velocity in i^{th} iteration, x_i is the particle position in i^{th} iteration, c_1, c_2 is the weight of local and global information respectively, w is the inertia constant, PB_i is the best position of the particle, GB_i is the best position of the swarm and $rand()$, $Rand()$ random value between [0,1].

III. PROBLEM FORMULATION

The objective of the problem at hand is to maximize the profits of VPP by trading energy in electricity market and simultaneously reduce load cost of users by applying a novel DR method at load side. The VPP design considered in this paper is a CVPP. The VPP aggregates PV plants on generation side, primary and secondary users on load side as shown in Fig.1. Primary users are composed of industrial and commercial with high electricity demands while secondary users are composed of residential load with low electricity demand.

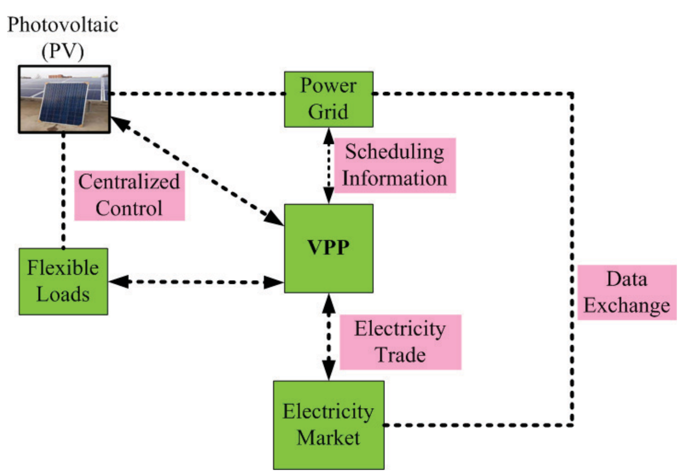

Fig. 1. VPP Configuration

Considering the variable nature of PV and uncertainty in load, PSO is used to optimize load dispatch using deterministic approach.

A. Virtual Power Plant

PV is the only RES generation unit considered in the VPP. There exists variability and inconsistency related with PV due to geographical location and sun intensity. The performance of VPP varies due to variability in PV's generation and uncertainty in load demand. To compensate for power deviation, VPP may be required to purchase electricity from the grid at a higher than market price.

At night, PV cannot generate electricity, so VPP purchases a substantial amount of power from the grid to sustain the power deficit. The hours of the day with such condition are classified into non-excessive zone. PV generates excess amount of power during day. There is extra energy even after dispatching power to all the users. The hours of the day with this condition are classified as excessive zone. So in day time, VPP sells its surplus power to grid. The grid selling price of electricity is higher than grid buying price. In order to maximize the profit of VPP, operator provides price incentives to users to shift the load from non excessive zone to excessive zone.

The objective is to maximize the economic benefits of VPP as given in Eq.3. The factors included are: the profit of VPP in DAM trading (U_t^{DAM}), benefits of supplying power to the load (U_t^L) and cost of power generation by PV (U_t^{PV}).

$$Max\ \ U = \sum_{t=1}^{24} U_t^{DAM} + U_t^L - U_t^{PV} \tag{3}$$

The operating cost of VPP in DAM trading is given by Eq. 4. P_t^{VPP}, is the power output of VPP. When $P_t^{VPP} \geq 0$ the VPP supplies power to grid and when $P_t^{VPP} < 0$ the VPP purchases power from grid.

From TOU prices, it can be observed that the VPP purchases electricity from the grid at a price that is 1.2 times the electricity selling price to the grid in DAM.

$$U_t^{DAM} = \begin{cases} P_t^{VPP} D_{s,t}^{DAM} & If\ P_t^{VPP} \geq 0 \\ P_t^{VPP} D_{p,t}^{DAM} & If\ P_t^{VPP} < 0 \end{cases} \tag{4}$$

$$P_t^{VPP} = P_t^{PV} - P_t^{pu} - P_t^{su} \tag{5}$$

$$P_{min}^{VPP} \leq P_t^{VPP} \leq P_{max}^{VPP} \tag{6}$$

$$D_{min}^{DAM} \leq D_{s,t}^{DAM} \leq D_{p,t}^{DAM} \leq D_{max}^{DAM} \tag{7}$$

In Eq.5, the power balance constraint for VPP is given. P_t^{PV} is the amount of power generated by PV at a particular time t, P_t^{pu} is the amount of power supplied to primary load and P_t^{su} is the amount of power supplied to secondary load. The amount of power that can be traded by VPP is given in Eq.6. P_{min}^{VPP} is the minimum power output of VPP (MW) and P_{max}^{VPP} is the maximum power output of VPP (MW). The price limits of VPP in DAM trading are given in Eq.7. where, $D_{p,t}^{DAM}$ and $D_{s,t}^{DAM}$ are the purchasing and selling price of VPP respectively. D_{max}^{DAM} and D_{min}^{DAM} are maximum and minimum price of VPP.

B. Consumers

Two types of consumers are considered in the system primary user and secondary user. The objective is to minimize the electricity cost of the consumers as given in Eq. 8. P_t^{pu} and P_t^{su} are the load demand of primary and secondary user respectively. D_t^{pu} and D_t^{su} are the prices at which VPP sells the energy to the primary and secondary users respectively.

$$Min\ \ U_t^L = \sum_{t=1}^{24} P_t^{pu} D_t^{pu} + P_t^{su} D_t^{su} \tag{8}$$

On the basis of profit maximization, the VPP operator offers price incentives to the users for shifting the load from non-excessive zone to excessive zone. The acceptable amount of load for transfer by consumers within each period is limited to 20% and 15% respectively for primary user and secondary user.

The range of power to be delivered to the consumers is given by Eq.9 and Eq.10 respectively. P_{min}^{pu} and P_{min}^{su} is the minimum load to be supplied for primary and secondary users respectively. While P_{max}^{pu} and P_{max}^{su} is the maximum amount of load to be supplied to primary and secondary consumers respectively. Electricity purchasing cost of load is modelled by Eq.11 and Eq.12. $D_{min}^{pu}$and D_{min}^{su} are the minimum prices at which electricity can be supplied to primary and secondary consumers respectively. While, D_{max}^{pu} and D_{max}^{su} gives the maximum prices at which electricity can be supplied to primary and secondary customers respectively.

$$P_{min}^{pu} \leq P_t^{pu} \leq P_{max}^{pu} \tag{9}$$

$$P_{min}^{su} \leq P_t^{su} \leq P_{max}^{su} \tag{10}$$

$$D_{min}^{pu} \leq D_t^{pu} \leq D_{max}^{pu} \tag{11}$$

$$D_{min}^{su} \leq D_t^{su} \leq D_{max}^{su} \tag{12}$$

IV. CASE STUDY

The VPP system considered in this study provides electricity to primary user and secondary user simultaneously. The PV is considered as only generation unit with a capacity of 80 MW. It is assumed that the total load of VPP is 50% of installed capacity. Fig.2. and Fig.3. represent the PV generation and load profile of primary and secondary users respectively. Table I gives the electricity price along with the upper and lower limit of the VPP's selling price to various loads. The electricity buying and selling price of the VPP follows the constraint mentioned in Eq.7.

TABLE I
VPP SELLING PRICE

Load type	Benchmark Electricity Price	Minimum Electricity Price	Maximum Electricity Price
Primary Load	1.3*$D_{p,t}^{DAM}$	1.1*$D_{p,t}^{DAM}$	1.5*$D_{p,t}^{DAM}$
Secondary Load	1.2*$D_{p,t}^{DAM}$	$D_{p,t}^{DAM}$	1.4*$D_{p,t}^{DAM}$

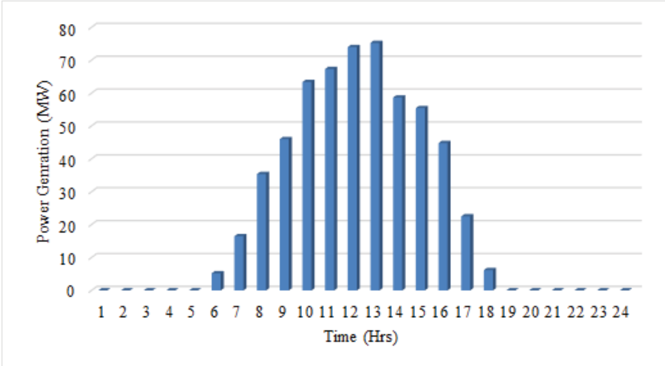

Fig. 2. PV Generation

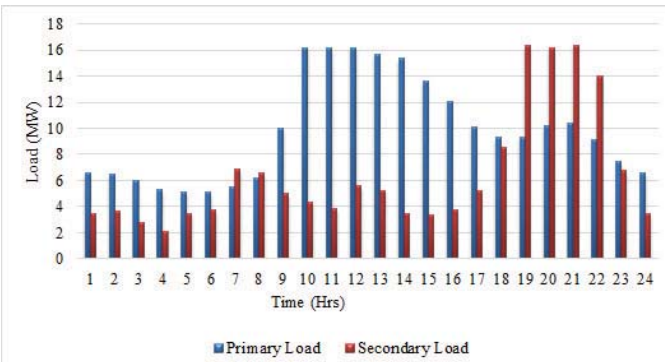

Fig. 3. Consumer Loads

Table I represents the upper and lower limits of VPP selling prices to primary and secondary users. Table II represents the TOU pricing of electricity in DAM. Market prices are given in USD/MWh. VPP purchases power from grid at 1.2 times of market price and sells additional power to grid at market price [16]. This purchase of energy at higher prices by VPP is due to uncertainty in generation and demand which causes certain bid deviation in its output [17]. In DAM, the VPP sells electricity to primary consumer at 1.3 times of VPP buying price and to secondary consumer at 1.2 times of VPP buying price.This selling price price of VPP can be varied between $1.1D_{p,t}^{DAM}$ to $1.5D_{p,t}^{DAM}$ for primary user and $D_{p,t}^{DAM}$ to $1.4D_{p,t}^{DAM}$ for secondary user.

Two types of zones are created as: i. excessive zone (E-zone) and ii. non-Excessive zone (NE-zone). The formation of these zones is dependent on the relation between VPP power output and load. These zones are presented in Table III. If P_t^{VPP} is negative, VPP purchases electricity from the power grid to meet the load demand. If P_t^{VPP} is positive, VPP has excess energy, so sells the excess energy to the grid. According to Table III, the whole day is further divided into 5 zones based on their classification as excessive or non excessive zones and the DAM pricing. Out of these, 3 zones are Non Excessive (NE)-zones and 2 zones are Excessive (E)-zones. At (21-06), (18-20), (17-18) and (20-21) hrs, VPP faces deficit energy and considered as NE-zone. At (06-07), (10-12), (7-10) and (12-17) hrs, VPP generates excess energy and considered as E-Zone.

TABLE II
TOU PRICES FOR INITIAL CASE

	Time Period (Hrs)	Market price (USD/MWh)	VPP Purchasing Price (USD/MWh)	Benchmark Load Price (USD/MWh)	
				Primary Users	Secondary Users
OFF peak	22:00 to 08:00	60	72	93.6	86.4
	11:00 to 13:00				
MID peak	08:00 to 11:00	80	96	124.8	115.2
	13:00 to 19:00				
	21:00 to 22:00				
ON peak	19:00 to 21:00	100	120	156	144

TABLE III
INITIAL CASE DETAILS

Time (Hrs)	PV Generation (MW)	Primary Load (MW)	Secondary Load (MW)	VPP Output (MW)	Remarks
21-06	5.19	57.64	43.27	-95.72	NE-Zone
06-07, 10-12	157.82	37.81	16.26	103.75	E-Zone
07-10, 12-17	401.41	99.22	36.82	265.37	E-Zone
18-20	0	19.54	32.5	-52.04	NE-Zone
17-18, 20-21	6.18	19.69	24.89	-38.4	NE-Zone

With higher electricity buying price, any shortfall in energy, exacerbates the VPP's profit. In order to maximize the profit, VPP will try to shift the users load from NE-zone to E-zone. In relation, the users are provided with price incentives in E-Zone. Also, electricity selling price of NE-zones are kept at benchmark load price. This encourages primary and secondary users to shift their load from NE-zone to E-zone. This methodology helps the primary and secondary users to satisfy their required demand while reducing the purchasing cost.

To provide electricity for primary and secondary users, VPP applies traditional scheduling with TOU prices in initial case. The VPP sells its energy at benchmark electricity price as given in Table I. The electricity selling and purchasing prices of VPP to its users are given in Table II. In the initial condition, the profit of VPP is observed to be 54386.272 (USD), the cost of purchasing energy for both the users is observed to be 26822.328 (USD) and 16932.384 (USD) respectively, for the whole day.

In this paper, VPP adopts PSO for implementing DR and optimizing its profit. The maximum acceptable change of load in a given zone can be 20% and 15% for primary and secondary users respectively. The limits for load scheduling are applied for considering the user comfort.

To reduce the complexity in the optimization process and going by the objective of maximizing VPP profit, the electricity price in NE-zone is kept at maximum electricity price. This will also provide incentive to the users to shift their load to E-zone. In E-zone, electricity price for load can vary between minimum and maximum allowable electricity price (price at which VPP sells the power to users).

The values for PSO parameters, inertia constant (ω) is considered to be 0.729, the acceleration constants (c_1, c_2) are considered to be 2.05 respectively. MATLAB is used for implementing the PSO method.

TABLE IV
BEST CASE PARAMETERS

Time (Hrs)	PV Generation (MW)	Primary Load (MW)	Secondary Load (MW)	VPP Output (MW)
21-06	5.19	57.64	43.27	-95.72
06-07, 10-12	157.82	45.372	18.699	93.749
07-10, 12-17	401.41	95.504	39.256	262.65
18-20	0	15.632	27.625	-43.257
17-18, 20-21	6.18	15.752	24.89	-34.462

The program is executed for 20 times and the output is a compilation of these readings. The average profit of VPP is observed to be 54967.925 (USD), the cost of purchasing energy for both the users is found to be better than the initial case, however the savings in cost is negligible. The results of PV generation, the load consumption of users, net VPP output for the best case after applying PSO is provided in Table IV.

TABLE V
COMPARISON OF INITIAL, AVERAGE AND BEST CASE

	VPP Profit	Net Increase in Profit	Percentage Improvement
Initial	54386.27		
Average	54967.925	581.655	1.0695%
Best	55000.62	614.35	1.1296%

In Table V, a comparison of economic benefits is presented for initial case, the average of compiled results and the best case from PSO execution. The VPP profit increases by 1.0695% on an average and by 1.1296% for best case.

VPP profit based on average results is increased by 581.655 (USD) in comparison to initial case as shown in Fig 4. Similarly, for best case the profit increases by 614.35 (USD) for VPP. The standard deviation obtained for the presented results is 25.5707 for VPP profit.

V. CONCLUSION

A VPP framework involving DR and energy trading is analysed in this research work. The objective of the study is to maximize the profit of VPP without increasing the cost of the users. Time zones are introduced along with the implementation of optimization process of PSO for achieving the objective. A day is divided into two time zones as E-zone and NE-Zone. PSO is applied for optimal load scheduling. The results indicate the successful implementation of the time zones concept. The standard deviation is minimum which indicates the similarity in the results obtained. A notable amount of profit is obtained by VPP with successful application of proposed DR method without harming the interests of the users.

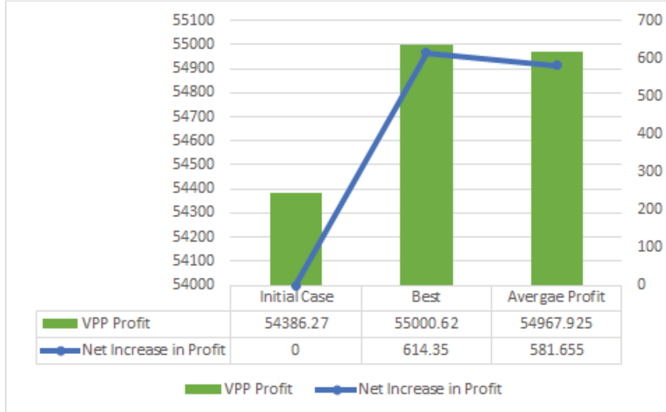

Fig. 4. Improvement of profit in VPP framework

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