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Optimal Scheduling of Battery in Micro-Grid with Renewable Energy Resources using TVAC-PSO

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Abstract: In the power system operation, coordination of battery require much attention. This is required to maintain the reliable operation of electrical energy network. The charging and discharging of battery is useful for micro-grid planner to decide when to charge and discharge. The integration of battery with micro-grid has considerable increase in profit of system. This work also present the operating cost of energy system only connected to main grid. This complex optimization is solved using random search techniques. It has found that optimization techniques implemented to this integrated system resulted in optimum solution. In this paper, time varying acceleration coefficients particle swarm optimization are used to find the optimum schedule of charging and discharging of battery with power purchased from grid. These swarm based techniques are tested on the test system and a obtained the system profit and cost using this methods. Time varying acceleration coefficients particle swarm optimization proved to be better among other variants.
Keywords: Wind enegy; Solar enegy; Energy storage system; Particle swarm optimization; Time varying acceleration coefficients.

I. INTRODUCTION

In the last few years, renewable based hybrid energy system has found attention due to increasing environmental concerns, energy demand, fuel prices and depletion of fossil fuels. In particular, solar and wind based generation systems have become sustainable and environmentally friendly options to supply power in isolated or off grid locations [1]. Solar photovoltaic (PV) energy conversion systems along with storage system have proved to be a very attractive method to provide electricity to the places like remote or off grid locations [2], residential households [3], off-grid location [4] and commercial buildings [5,6]. However, PV generation has a low energy conversion efficiency and cost of electricity per kWh is high. This led to a substantial growth in wind based power generation.

Numerous researches focus on feasibility and optimum sizing of the wind based systems [7–9]. However, the major drawbacks for both wind and solar energy sources are their stochastic nature which raises concern about the reliability of power to the user. Therefore, to enhance the reliability, hybridization of both wind and solar energy is a suitable alternative. One’s weakness can be compensated by the strengths of another. However, it increases the complexity of the system [10]. Stand alone solar-wind based hybrid energy systems have been analyzed in various researches in terms of cost effectiveness [11–13]. The biggest drawback of a stand alone solar-wind based energy system is its dependency on power back-up due to the irregular nature of both wind and solar resources. In case of a stand-alone hybrid system generally back-up is provided by diesel generator or energy storage devices such as batteries or ultra-capacitors [14-16].

The major contribution of this is to design a cost effective and reliable hybrid PV-wind energy system with battery storage to meet the electrical load demand of small area which has enough natural resources [17-18]. The mathematical modelling of various components and operational strategy in the proposed system have been discussed in detail. The detail cost analysis of the proposed hybrid system is performed by applying HCPSO algorithms. For optimal scheduling, results obtained by applying these different methods have been compared. Moreover, a critical case such as failure of one generating unit has also been performed to test the reliability of the hybrid energy system.

The intent of this research work have been summarized below:

For the bi-directional flow of energy between the storage and grid, the calculation for satisfying the load demand becomes complex.

The integration of battery with micro-grid has considerable increase in profit of system. This work also present the operating cost of energy system only connected to main grid. This complex optimization is solved using random search techniques. It has found that optimization techniques implemented to this integrated system resulted in optimum solution.

The scheduling of the electric storage with the grid having solar and wind palnt for different charge/discharge rate has been calculated.

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In this paper, optimal solution of battery charging and discharging with their constraints is obtained and power from main grid, wind and solar plant is considered. The constraints for the battery and load balance are also satisfied with the help of a popular swarm based technique, PSO and velocity modified variants [19-23]. The test system is applied on one test system. The optimizations of the problem and simulation results have been obtained.

This paper is organized as follows: Section II describes the mathematical formulation of solar, wind and battery system. Section III presents a brief overview of PSO and its variants. In section IV the simulation is carried out for a test system having solar, wind and battery and result is discussed. In section V the conclusion is given showing the feasible solution of the problem and future work.

II. MATHEMATICAL MODELLING

The renewable energy resouces can be categorized as:

In this paper, modeling of renewable energy resources with battery model is used.

A. Solar generation (PV)

The energy generation from solar cell or photovoltaic cell is called as the green energy technology. The PV plant generated power which is widely depend upon the solar radiation, temperature and atmospheric condition. However, uncertainty is observed in the solar radiation due to cloud and it is depend upon weather conditions. Shading effect is power generation from PV plant. The power generated from PV plant is expressed as:

$$P_{gs} = P_r\{1 + (T_{ref} - T_{amb}) \times \alpha\} \times \frac{S_i}{1000} \qquad (1)$$

where

P_r is its rated power of PV generation.

T_{ref} is the reference temperature.

T_{amb} is the ambient temperature.

α is temperature coefficient .

S_i is the incident solar radiation.

The power sharing or generation from PV plant is evaluated during scheduling as:

$$E_{ss} = \sum_{j=1}^{m} P_{gs_j} \times U_{s_j} \qquad (2)$$

where

P_{gs_j} Power is available from j^th solar plant

U_{s_j} Represents the status of j^th PV plant is operating or non-operating zone.

The operating cost of PV unit is formulated as:

$$F_{sc} = \sum_{j=1}^{m} E_{pu_j} \times P_{gs_j} \times U_{s_j} \qquad (3)$$

where

E_{pu_j} is per unit cost of j^th PV plant.

B. Wind Enegy

The wind energy gration is also green energy technology which is widely used by mainy countries in world. The power generation from wind turbines is dependent upon the velocity of air which is further dependent upon environment conditions. The output power of the wind energy conversion system is depend upon the rated wind speed, cut in and cut out wind speed. The output of the WECS with a given wind speed input may be stated as [11]

$$p = 0 \text{ ,for } v < v_i \qquad (4)$$

$$p = p_r \frac{(v - v_i)}{(v_r - v_i)} \text{ ,for } v_i \qquad (5)$$

$$p = p_r \text{ , for} \qquad (6)$$

where

p WECS output power (kilowatt);

w_r WECS rated power;
v_i cut-in wind speed (miles/hour or miles/second);
v_r rated wind speed;
v_o cut-out wind speed.

C. Modelling of battery system

The power storage system consists of constraints which must be satisfied throughout process. The detail regarding equality and inequality constraints of electrical storage system are given below.

Storage limits:

$$P_{storage}(t) = CAP_{storage} \quad \forall t \qquad (7)$$

Maximum storage discharge limits:

$$PD_{storage}(t) \le (0.4 \times CAP_{storage}) \times X(t) \quad \forall t,\ X \in \{0,1\} \qquad (8)$$

Maximum storage charge limits:

$$PC_{storage}(t) \le (CAP_{storage}) \times Y(t) \quad \forall t, Y \in \{0,1\} \qquad (9)$$

where, X and Y are binary variables to represented discharge and charge of energy storage system.

The battery cannot charge and discharge at the same time in each time slice:

$$X(t) + Y(t) \le 1 \quad \forall t, Y \text{ and } X \in \{0,1\} \qquad (10)$$

Maximum discharge limits (kW) in each period:

$$PD_{storage}(t) - P_{storage}(t-1) \le 0 \quad \forall t \qquad (11)$$

Storage battery maximal charge limits (kW) in each period ‘‘t’’, considering the battery state storage in period t-1:

$$PC_{storage}(t) - P_{storage}(t-1) \le CAP_{storage} \quad \forall t \qquad (12)$$

State balance of the battery:

$$P_{storage}(t) = P_{storage}(t-1) - PD_{storage}(t) + PC_{storage}(t-1) \quad \forall t \ (13)$$

Initial energy storage system:

$$P_{storage}(t=0) \le (0.4 \times CAP_{storage}) \qquad (14)$$

Equality constraint including battery:

$$PE_{Demand}(t) = P_g(t) - PD_{storage}(t) - PC_{storage}(t) \quad \forall t \qquad (15)$$

In this section, detail of constraints of battery with their parameter values which are vary with charging and discharging conditions. The battery parameters depend on manufacturer’s characteristics data while parameters are approximately constant during 20%SOC to 100% SOC.

D. Objective function

The objective function of micro-grid having renewable energy system and battery is to maximize the benefit during the schedule period. The total obtaind benefit for this system is evaluated from equaton (16), which is consist of renevenue obtained by selling of energy which is depend on generation and selling price while the other is the cost of energy production. The objective function of proposed system for 24 hour schedule is given as:

$$\text{Obj=max Benefit = Revenue -Cost} \qquad (16)$$

In (16), the revenue is obtained when power is selling from micro-grid to main grid during some hours of the day or off peak load and expressed as:

$$REVENUE = \sum_{t=1}^{T} ep(t) \times Grid_{sell}(t) \qquad (17)$$

The cost of this energy system is consists of four variables corresponding to the costs of electricity production by the thermal (CostConv(i,t)), electricity purchased from upstream network (CostBuy(t)), the cost of battery storage (Coststorage(t)), the cost of wind energy (Costwind(t)) and the solar cost (CostSolar(t)):

$$Cost = \sum_{t=1}^{T}\sum_{i=1}^{N} Cost_{conv}(i,t) + \sum_{t=1}^{T} Cost_{buy}(t) + \sum_{t=1}^{T} Cost_{storage}(t) + \sum_{t=1}^{T} Cost_{solar}(t) + \sum_{t=1}^{T} Cost_{wind}(t) \qquad (18)$$

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III. TIME VARYING ACCELERATING COEFFICENTS-PARTICLE SWARM OPTIMIZATION

A. Review of PSO

PSO is a metaheuristic technique aiming at obtaining satisfactory results in practical scheduling problem. Such an approach is totally based on the selection of its appropriate parameters. Thus, above discussed qualities should be desired for such a metaheuristic technique [19].

For the j-dimension of solution area, the location P_i and velocity V_i of i^{th} solution vector is listed as [23]

$$\mu_i = \left[\mu_{i,1}, \mu_{i,2}, \mu_{i,3}, \ldots\ldots \mu_{i,j}\right] \tag{19}$$

$$V_i = \left[V_{i,1}, V_{i,2}, V_{i,3}, \ldots\ldots V_{i,j}\right] \tag{20}$$

The local best value of each particle can be expressed as

$$\mu_i^{best} = \left[\mu_{i,1}^{best}, \mu_{i,2}^{best}, \mu_{i,3}^{best}, \ldots\ldots \mu_{i,j}^{best}\right] \tag{21}$$

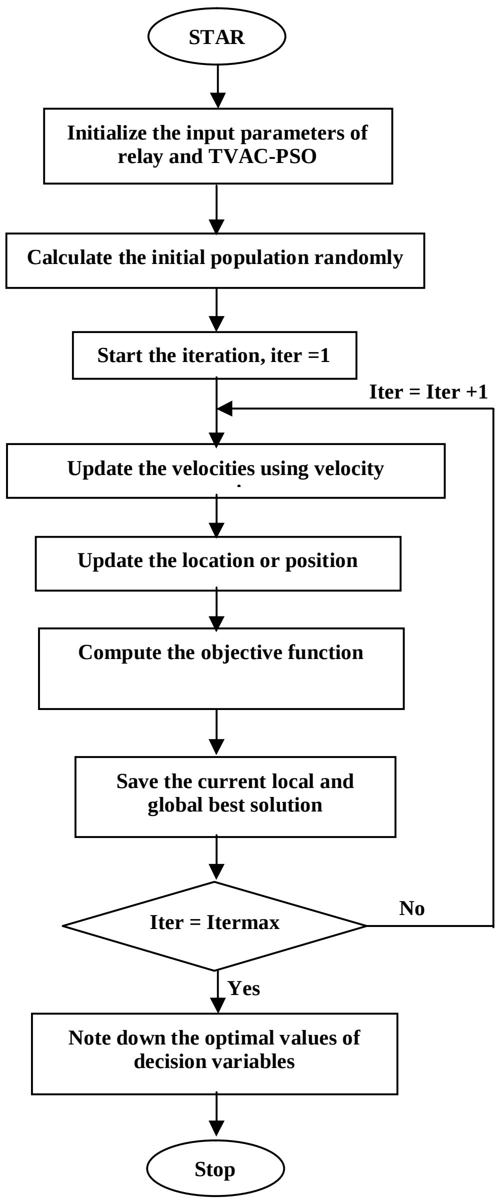

Fig. 1. Flow-Chart for TVAC-PSO.

W	Inertia weight.
w^{max}, w^{min}	Maximum and minimum inertia weight.
C_1, C_2	Acceleration cofficent.
$\mu_{s,i}^{k}$	Position of s^{th} particle of i^{th} dimension at k^{th} iteration.
$V_{s,i}^{k}$	Velocity of s^{th} particle of i^{th} dimension at k^{th} iteration.
μ_i^{Gbest}	Global best position of i^{th} dimension.
$\mu_{s,i}^{best}$	Local best position of s^{th} particle of i^{th} dimension.
IT	Iteration number.
IT_{max}	Maximum number of iteration.

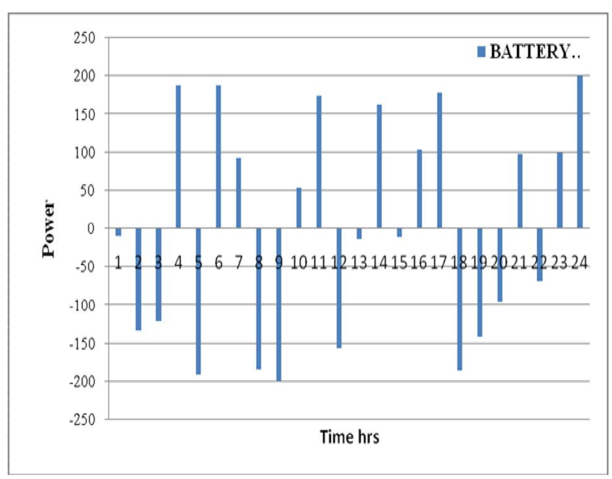

Fig. 2 Charging and discharging of battery for 24 hour.

(24)

Thus, positional coordinates of each of the particle in swarm is expressed as

$$\mu_{j,i}^{k+1} = \mu_{j,i}^{k} + V_{j,i}^{k+1} \tag{25}$$

B. Overview of TVAC-PSO

In PSO when search process reaches the local search area then convergence the rate slow for exploitation and does not find best solution. The rate of convergence is greatly affected by the variable acceleration coefficients. This leads to the implementation of time varying acceleration coefficients PSO (TVAC-PSO). The flow chart for TVAC-PSO is shown in Fig. 1. The acceleration coefficients are constants in conventional PSO. These coefficients are needed to be updated to improve the solution. The cognitive parameter is of declining and social parameter is of inclining behavior as iteration proceeds. Comparatively large value of the social parameter relating to cognitive parameter corresponds to the false convergence at some local value while comparatively large values

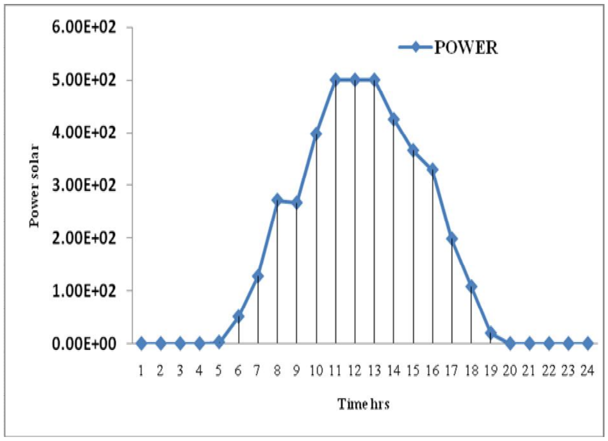

Fig. 3 Power generation from solar plant.

IV. RESULT AND DISCUSSION

The TVAC-PSO have been applied for the reduction of wind plant, battery and power purschase from grid. This reduction in objective function i.e. operating cost of system that include charging and discharging of battery with satisfied battery and all other balance constraints is the main purpose of this paper. The TV-AC variants based PSO technique is applied on a test system. This test system contains 10 wind plant (100kw), solar plant (10kw), battery (500kw) while input data of battery like CB (rated capacity) , scion (intial charge) , socmax (maximum charge), socmin (minimum charge) is 500, .5, .95 and .2.

Furthermore, the parameter setting of TV-AC PSO is taken same as in [27]. This optimization technique is applied to get optimum schedule of power supply by grid and battery. This is used to schedule the battery for 24 hour. The power generation from solar plant during the day time 4-7th and night from 7-3rd lower or near to zero while maximum at day time noon and it is illustrated in Figure 2. The power generation from wind plants is vary throughout the day and night, it is dependent upon the wind speed and it is illustrated in Figure 3.

The operation of battery during 24 hour and the optimum

solution to charge and discharge the battery is represented in Figure 4. The power taken from grid is minimum when power generation from solar and wind plant are at maximum level and it may sold to grid if power generation is more than demand and it is shown in Figure 5. The cost and profit obtained at each time interval is dependent on generation, demand and selling price of energy and it is represented in Figure 5 and 6.

V. CONCLUSION

In this paper, time varying acceleration coefficients particle swarm optimization is tested on the problem of optimal scheduling of battery and power purshased from grid. The output of simulation shows that it provide feasible solution for the input parameters of battery. This paper presented the continuous solution in terms of charging and discharging of battery. The test system used for the testing purpose is using one test system. Particle swarm optimization is a popular swarm based technique. A conventional PSO and its variants *i.e.* particle swarm optimization and TVAC-PSO is also discussed. The result obtained by implementation of TVAC-

PSO is provide in above section. This work can be continued to the larger number of system and including the integer variable to make model more realistic and optimization using more variants of PSO.

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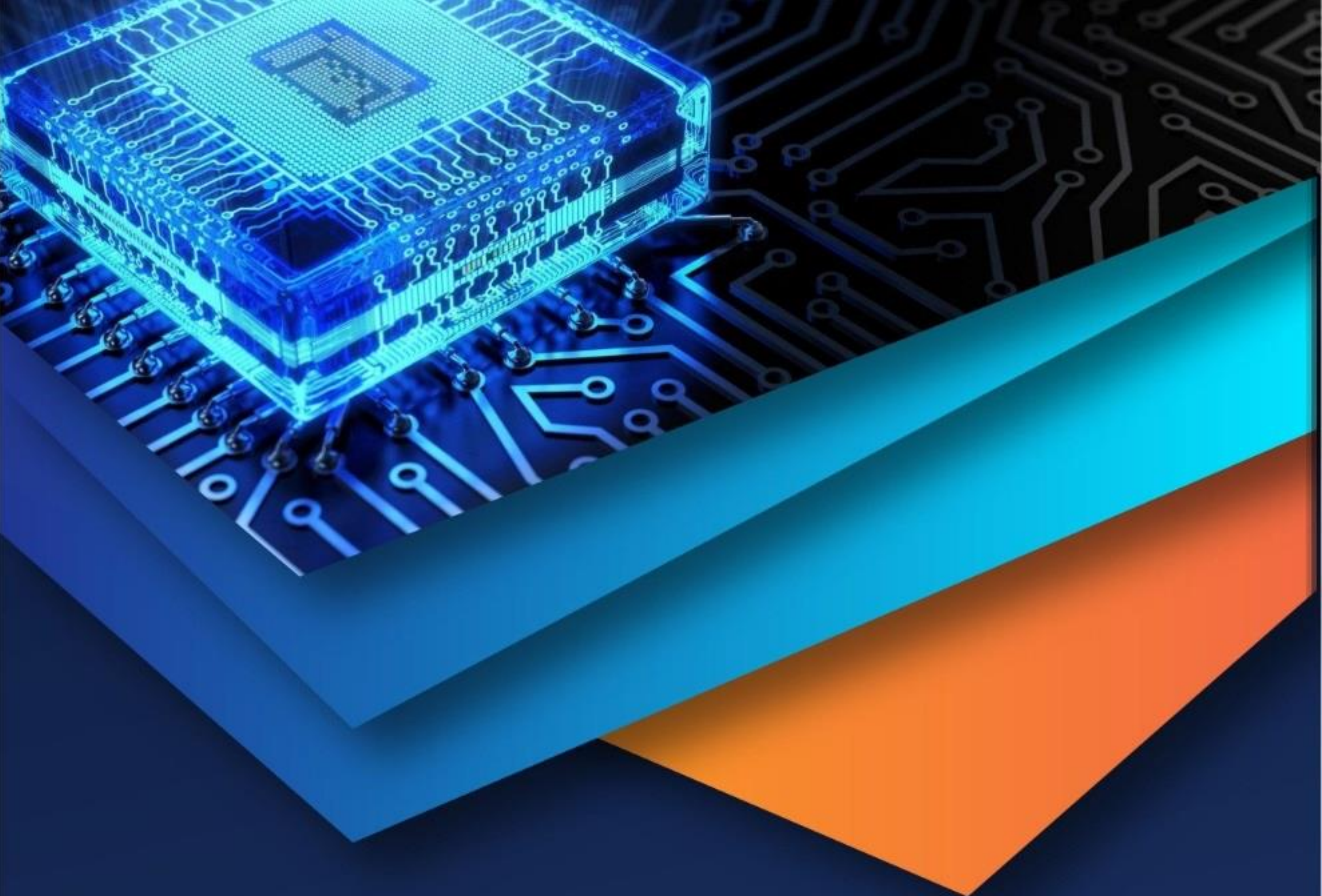

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