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Integration of Renewable Energy System and Efficient Demand Side Response in Smart Grids

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Abstract: *The Smart Grid, regarded as the next generation power grid, uses two-way flows of electricity and information to create a widely distributed automated energy delivery network. In this article, we survey the literature till 2011 on the enabling technologies for the Smart Grid. We explore three major systems, namely the smart infrastructure system, the smart management system, and the smart protection system. We also propose possible future directions in each system. Specifically, for the smart infrastructure system, we explore the smart energy subsystem, the smart information subsystem, and the smart communication subsystem. For the smart management system, we explore various management objectives, such as improving energy efficiency, profiling demand, maximizing utility, reducing cost, and controlling emission. We also explore various management methods to achieve these objectives. For the smart protection system, we explore various failure protection mechanisms which improve the reliability of the Smart Grid, and explore the security and privacy issues in the Smart Grid. The design of efficient Demand Response (DR) mechanisms for the residential sector entails significant challenges, due to the large number of home users and the negligible impact of each of them on the market. We propose a Multi objective model for the DSM in smart grid where a set of competing aggregators act as intermediaries between the utility operator and the home users. The operator seeks to minimize the smart grid operational cost and offers rewards to aggregators toward this goal. Profit-maximizing aggregators compete to sell DR services to the operator and provide compensation to end users in order to modify their preferable consumption pattern using optimization strategies. Finally, end-users seek to optimize the trade-off between earnings received from the aggregator and discomfort from having to modify their pattern. In this context, interruptible loads are consumers who agree to be interrupted, as required and within constraints, to maintain system security or reduce market prices, and are compensated by paying reduced tariffs. These consumers are generally large industrial customers with their own backup generation or those that can easily reschedule production. They can also be residential customers who want to save on their electricity bill, or retail electricity providers that aggregate the consumption of small customers. In accordance to contractual arrangements, the utility can directly interrupt supply to the customer, or the customer can disconnect or reduce consumption at the direct request of the utility.*

Keywords: Smart Grid, Demand Response, smart management system, DSM

I. INTRODUCTION

Aghaei, Jamshid, et al. (2013)In this paper, today's, policy makers, governments, and academic experts in flourishing societies are interested in employing power systems considering high reliability, quality, and efficiency factors. Moreover, climatic concerns force power system appliers to utilize these systems more environmental friendly. To obtain the mentioned aims, MGs (micro grids) act as key solutions. MGs are invented not only to operate power systems more reliable and efficient but also to penetrate CHP (combined heat and power)-based DG (distributed generation) into power systems with an optimal control on their generation. This paper presents a new optimal operation of a CHP-based MG comprising ESS (energy storage system), three types of thermal power generation units, and DRPs (demand response programs). In this paper, DRPs are treated as virtual generation units along with all of realization constraints. In a multi-objective self-scheduling optimization problem of a MG, the first objective deals with minimizing total operational cost of the CHP-MG in an OPF-based formulation and the second refers to the emission minimization of DGs. The proposed model implements a simple MIP (mixed-integer programming) that can be easily integrated in the MGCC (MG central controller). The effectiveness of the proposed methodology has been investigated on a typical 24-bus MG[1]. Faria, Pedro, et al. (2013) In this paper, price-based demand response is applied to electric power systems. Demand elasticity and consumer response enables load reduction. The methodology is implemented in the DemSi demand response simulator. Competitive electricity markets have arisen as a result of power sector restructuration and power system deregulation. The players participating in competitive electricity markets must define strategies and make decisions using all the available information and business opportunities[2]. Gkatzikis, Lazaros, et al. (2013) In this paper, the design of efficient Demand Response (DR) mechanisms for the residential sector entails significant challenges, due to the large number of home users and the negligible impact of each of them on the market. In this paper, they introduce a hierarchical market model for the smart grid where a set of competing aggregators act as intermediaries between the utility operator and the home users. The operator seeks to minimize the smart grid operational cost and offers rewards to aggregators toward this goal. Profit-maximizing aggregators compete to sell DR services to the operator and provide compensation to end-users in order to modify their preferable consumption pattern. Finally, end-users seek to optimize the tradeoff between earnings received from the aggregator and discomfort from having to modify their pattern. Based on this market model, they first address the benchmark scenario from the point of view of a cost-minimizing operator that has full information about user demands. Then, they consider a DR market, where all entities are self-interested and non-cooperative. The proposed market scheme captures the diverse objectives of the involved entities and, compared to flat pricing, guarantees significant benefits for each. Using realistic demand traces, they quantify the arising DR benefits. Interestingly, users that are extremely willing to modify their consumption pattern do not derive maximum benefit[3]. Joo, Jhi-Young, et al. (2013) In this paper concerns mathematical conditions under which a system-level optimization of supply and demand scheduling can be implemented as a distributed optimization in which users and suppliers, as well as the load serving entities, are decision makers with well-defined sub-objectives. We start by defining the optimization problem of the system that includes the sub-objectives of many different players, both supply and demand entities in the system, and decompose the problem into each player's optimization problem, using Lagrange dual decomposition. A demand entity or a load serving entity's problem is further decomposed into problems of the many different end-users that the load serving entity serves. By examining the relationships between the global objectives and the local/individual objectives in these multiple layers and the optimality conditions of these decomposable problems, they define the requirements of these different objectives to converge. We propose a novel set of methods for coordinating supply and demand over different time horizons, namely day-ahead scheduling and real-time adjustment. We illustrate the ideas by simulating simple examples with different conditions and objectives of each entity in the system[4]. Kennel, Fabian, et al. (2013) In this paper presents an energy management system for smart grids with electric vehicles based on hierarchical model predictive control (HiMPC). The energy management system realizes load-frequency control (LFC), an economic operation and an electric vehicle integration into the smart grid. The main component is the HiMPC, which allows covering different time scales, regarding constraints (e.g. power ratings) and predictions (e.g. on renewable generation), as well as rejecting disturbances (e.g. due to fluctuating renewable generation) based on a systematic model- and optimization-based design. For the electric vehicle integration, an aggregator is proposed as link between HiMPC and individual vehicle. The aggregator in particular provides predictions to the HiMPC on the availability of electric vehicles for LFC based on the current mobility demand and the statistical mobility behavior of the vehicle users. Throughout the paper, the energy management system is evaluated for the smart grid of an intermediate city[5]. Marzband, Mousa, et al. (2014) in this paper, both performance optimization and scheduling of the distributed generation (DG) are relevant implementing an energy management system (EMS) within Microgrid (MG). Furthermore, optimization methods need to be applied to achieve maximum efficiency, improve economic dispatch as well as acquiring the best performance. This paper proposes an optimization method based on gravitational search algorithm to solve such problem in a MG including different types of DG units with particular attention to the technical constraints. This algorithm includes the implementation of some variation in load consumption model considering accessibility to the energy storage (ES) and demand response (DR). The proposed method is validated experimentally. Obtained results show the improved performance of the proposed algorithm in the isolated MG, in comparison with conventional EMS. Moreover, this algorithm which is feasible from computational viewpoint, has many advantages as peak consumption reduction, electricity generation cost minimization among other.[6]

II. METHODOLOGY

The DR may be formulated as a nonlinear constrained problem. Both convex and non-convex DR problems have been modeled in this paper. The convex DR problem assumes quadratic cost function along with system power demand and operational limit constraints. The practical non-convex DR (NCELD) problem, in addition, considers generator nonlinearities such as valve point loading effects, prohibited operating zones, ramp rate limits, and multi-fuel options.

2.1 DR-QCTL

The objective function of DR problem may be written as

$$Ft = \min\left(\sum_{i=1}^{m} Fi(Pi)\right. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

$$= \mathrm{m} \sum_{i=1}^{m} ai + biPi + ciP_i^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

where Fi(Pi) is the ith generator's cost function, and is usually expressed as a quadratic polynomial; at, b,. and c, are the cost coefficients of the ith generator; m is the number of committed generators to the power system; Pi is the power output of the ith generator. The DR problem consists in minimizing Ft subject to the following constraints

A. Real Power Balance Constraint:

$$\sum_{i=1}^{m} Pi - PD - Pl = 0, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

The transmission loss P_L may be expressed using B-coefficients as

$$PL = \sum_{i=1}^{m}\sum_{i=1}^{m} PiBijPj + \sum_{i=1}^{m} BoiPi + Boo, \ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

B. Generator Capacity Constraints

The power generated by each generator shall be within their lower limit P,-"^{min} and upper limit i^^{max}. So that

$$P_i^{min} \le Pi \le P_i^{max} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.5)$$

The objective function Ft of this type of DR problem is same as mentioned in DRQCTL (4.1). Here the objective function is to be minimized subject to the following constraints.

1) Real Power Balance Constraint: The real power balance constraint remains the same as in (4.2).

2) Generator Capacity Constraints: This constraint remains unchanged as given in (4.4).

C. Ramp Rate Limit Constraints

The power generated. I), by the ith generator in certain interval may not exceed that of previous interval If Pio by more than a certain amount UR;.the up-ramp limit and neither may it be less than that of the previousinterval by more than some amount DRi the down-ramp limit of the generator. These give rise to the following constraints. As generation increases

Pi - Pi0 < URL

As generation decreases

Pio - Pi <DRi

And

$$\max\left(P_i^{min}, Pio - Dri\right) \le Pi \le \min\left(P_i^{max}, Pio + URi\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.6)$$

D. Prohibited Operating Zone

The prohibited operating zones are the range of output power of a generator where the operation causes undue vibration of the turbine shaft. Generally such vibration occurs at the point of opening or closing of the steam valve which might cause damage to the shaft and bearings. It is difficult to determine the exact prohibited zone by actual testing or from operating records. Normally operation is avoided in such regions. Hence mathematically the feasible operating zones of unit can be described as follows:

$$P_i^{min} \le Pi \le P^l i, 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.7)$$

$$P^u i, j-1 \le Pi \le P^l i, j; j = 2,3, \ldots ni \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.8)$$

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$P^u i, n_i \leq P_i \leq P_i^{max}$ …………………………………..………. (4.9)

where j represents the number of prohibited operating zones of unit i. $P_{i,j-1}^u$ is the upper limit of (j - l)th prohibited operating zone of jth unit. Pf - is the lower limit of jth prohibited operating zone of ith unit. Total number of prohibited operating zone of ith unit is m.

2.2 DRVPL

In DR with "valve point loadings", objective function Ft is represented by a more complex formula, given as Ft in (9) at the bottom of the page. Variation of fuel cost due to valve point loading with the change of generation value Pi is shown in Fig. The objective of DRVPL is to minimize Ft of (4.9) subject to the same set of constraints given in (4.2) and (4) as in DRQCTL.

2.3 DRVPLMF

For a power system with m generators and Np fuel options for each unit, the cost function of the generator with valve-point.

$Ft = \min\left(\sum_{i=1}^{m} Fi(pi)\right) = \min\left(\sum_{i=1}^{m} ai + bipi + ciC_i^P + |eiXSin\{fix(P_i^{min} - Pi)\}|\right)$………… (4.10)

loading is expressed as (4.10) at the bottom of the page, where P$m and In,laK are the minimum and maximum power generation limits of the jth generator with fuel option k, respectively;

b_{ik}, C_{ik}, (i_{ik}, and J,k are the fuel-cost coefficients of generator i for fuel h.

The above objective function is to be minimized subject to the same constraints as mentioned in (4.2)-(4.4).

E. Calculation for Slack Generator

Let N committed generating units deliver the power output subject to their respective energy balance constraints (4.2) and the capacity constraints (4.4). Assuming the power loadings of first (N-l) generators as specified, the power level of Nth generator (i.e., slack generator) is given by

$PN = PD + PL - \sum_{i=1}^{(N-1)} Pi,$ ……………………………………………………(4.11)

The transmission loss Pi is a function of all the generator outputs including the dependent generator and it is given by

$PL = \sum_{i=1}^{N-1}\sum_{i=1}^{N-1} PiBijPj + 2PN(\sum_{i=1}^{N-1} BNiPi) + BNNP_N^2 + \sum_{i=1}^{N-1} BoiPi + BoNPN + B00$......(4.12)

Expanding and rearranging, (4.11) becomes (4.13) at the bottom of the page. The loading of the dependent generator (i.e., Nih) can then be found by solving (4.13) using standard algebraic method. Above equation can be simplified as

$XP_N^2 + YPN + Z = 0$

where we see the last equation at the bottom of the page. The positive roots of the equation are obtained as

PN=$\frac{-Y \pm \sqrt{Y^2 - 4XZ}}{2X}$, $where\ Y2 - \$XZ \geq 0$……………………………………………………. (4.13)

Fi(Pi) =a_{ik} + b_{ik}*Pi* + Cifcif + *e-ik* x Sm{/$_{tfc}$ x (f$F* - P$_{;fc}$)}| »/ i^r< P; <*FT***for fuel option* fc; *k* = 1.2.... N_F

$BNNP_N^2 + (2\sum_{i=1}^{N-1} BNiPi + B0N - 1)PN + (PD + \sum_{i=1}^{N-1}\sum_{j=1}^{N-1} PiBijPj + \sum_{i=1}^{N-1} BoiPi - \sum_{i=1}^{N-1} Pi + B00) = 0$ (4.14)

$$X = BNN$$

$Y = (2\sum_{i=1}^{N=1} BNIPi + Bon - 1)$……………………………………………………………... (4.15)

$Z = (PD + \sum_{i=1}^{N-1} B0pPi - \sum_{i=1}^{N-1} pi + Boo)$…………………………..………………………… (4.16)

To satisfy the equality constraint (4.11), the positive root of (4.15) is chosen as output of the JVth generator.

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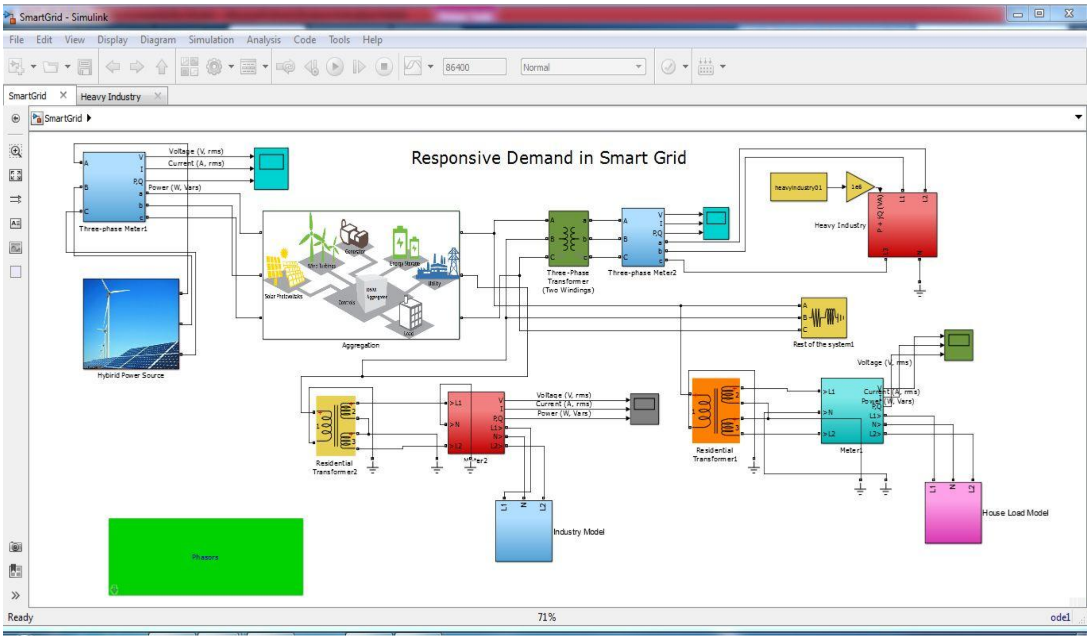

Fig 1 Simulink model for Demand Response Management

III. Results

The distribution generation from the various renewable sources like Solar, Fuel Cell, wind and UPS is given in table 5.1. Power distribution is transfer from 23:59:00 from 0: 34:00

Time	Use [kW]	Gen [kW]	Grid [kW]	Solar [kW]	Fuel Cell[KW]	UPS[KW]	Wind[KW]
23:59:00	5.75323333	0	5.7535	8	1	1	1
00:00:00	5.72795	0	5.72795	8	1	1	1
00:01:00	5.83343333	0	5.83343333	8	1	1	1
00:02:00	4.97116667	0.0008	4.97196667	8	1	1	1
00:03:00	2.71556667	0.00301667	2.71858333	8	1	1	1
00:04:00	2.0304	0.00268333	2.03308333	8	1	1	1
00:05:00	1.79393333	0.00255	1.79648333	8	1	1	1
00:06:00	1.79411667	0.00251667	1.79663333	8	1	1	1
00:07:00	1.78975	0.00255	1.7923	8	1	1	1
00:08:00	1.78613333	0.0026	1.78873333	8	1	1	1
00:09:00	1.78418333	0.00253333	1.78671667	8	1	1	1
00:10:00	1.78495	0.00256667	1.78751667	8	1	1	1
00:11:00	1.78993333	0.00248333	1.79241667	8	1	1	1
00:12:00	1.78591667	0.00248333	1.7884	8	1	1	1
00:13:00	4.50633333	0.00065	4.50698333	8	1	1	1
00:14:00	5.30905	0	5.30905	8	1	1	1
00:15:00	4.99165	0	4.99165	8	1	1	1
00:16:00	4.7157	0	4.7157	8	1	1	1
00:17:00	4.80088333	0	4.80088333	8	1	1	1
00:18:00	4.82953333	0	4.82953333	8	1	1	1
00:19:00	4.65313333	0	4.65313333	8	1	1	1
00:20:00	4.5949	0	4.5949	8	1	1	1
00:21:00	4.59211667	0	4.59211667	8	1	1	1

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00:22:00	4.58578333	0	4.58578333	0	1	1	1
00:23:00	4.54773333	0	4.54773333	0	1	1	1
00:24:00	4.55348333	0	4.55348333	0	1	1	1
00:25:00	4.54546667	0	4.54546667	0	1	1	1
00:26:00	2.97341667	0.00183333	2.97525	0	1	1	1
00:27:00	1.47746667	0.00331667	1.48078333	0	1	1	1
00:28:00	0.57851667	0.00263333	0.58115	0	1	1	1
00:29:00	0.57456667	0.00263333	0.5772	0	1	1	1
00:30:00	0.6984	0.00263333	0.70103333	0	1	1	1
00:31:00	0.73235	0.00258333	0.73493333	0	1	1	1
00:32:00	0.73246667	0.00261667	0.73508333	0	1	1	1
00:33:00	0.65255	0.00248333	0.65503333	0	1	1	1
00:34:00	0.6605	0.00208333	0.66258333	0	1	1	1

Table 1 Subset of Data taken for distributed generation from various sources such as solar, fuel cells, wind, UPS etc

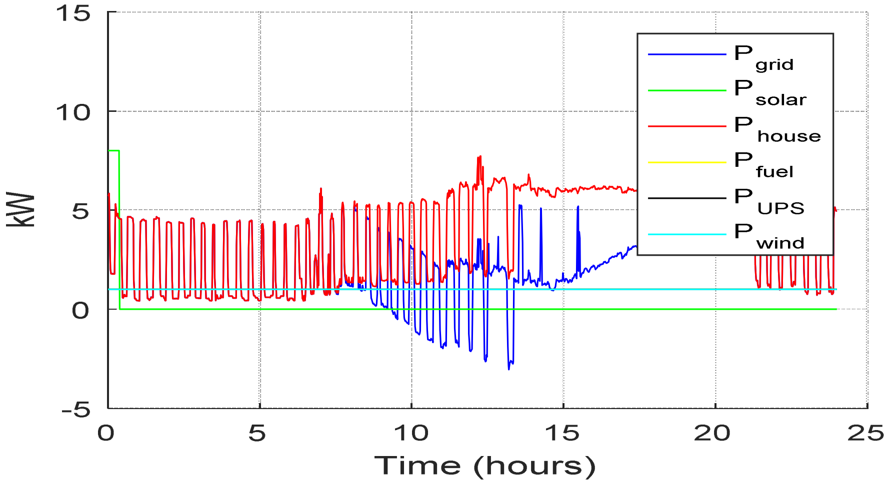

Fig 2 Demand (KW) P_{house} from houses and Grid Response for various sources Solar, House, fuel and Wind sources.

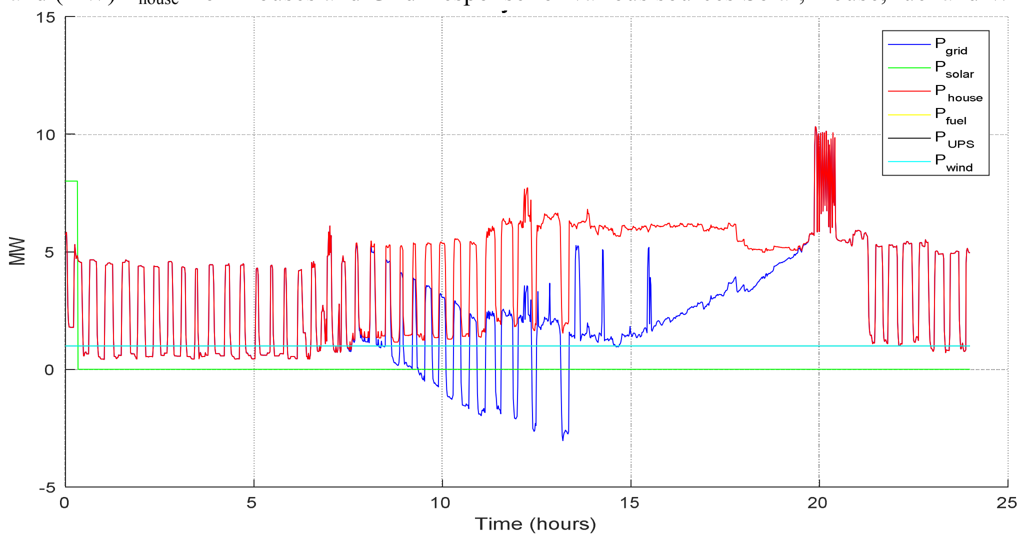

Fig 3 Visualization of Heavy industry Demand Response

Fig 5.1 & 5.2 shows the visualization of heavy industry demand response. The demand response is given by different industry. The local society .personal office & home demand response is given in the Simulink design.

IV. Conclusion

This Work presents a Particle Swarm optimization (PSO) algorithm to solve both convex and non-convex economic load dispatch (ELD) problems of thermal plants. The proposed methodology can take care of economic dispatch problems involving constraints such as transmission losses, ramp rate limits, valve point loading, multi-fuel options and prohibited operating zones. Biogeography deals with the geographical distribution of biological species. Mathematical models of biogeography describe how a species arises, migrates from one habitat to another and gets wiped out. PSO has some features that are in common with other biology-based optimization methods, like genetic algorithms (Gas). This algorithm searches for the global optimum mainly through two steps: migration and mutation. The effectiveness of the proposed algorithm has been verified on four different test systems, both small and large, involving varying degree of complexity. Compared with the other existing techniques, the proposed algorithm has been found to perform better in a number of cases. Considering the quality of the solution obtained, this method seems to be a promising alternative approach for solving the ELD problems in practical power system. The PSO method has been successfully implemented to solve different convex and non-convex ELD problems with the generator constraints. The PSO algorithm has the ability to find the better quality solution and has better convergence characteristics, computational efficiency, and robustness. Many nonlinear characteristics of the generator such as ramp rate limits, valve point loadings, multi-fuel options, prohibited operating zone, etc. have been considered. It is clear from the results obtained by different trials that the proposed PSO method has good convergence property and can avoid the shortcoming of premature convergence of other optimization techniques to obtain better quality solution. Due to these properties, the PSO method in the future can be tried for solution of complex unit commitment, dynamic ELD problems in the search of better quality results

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