Revista Publicando, 5 No 15. (2). 2018, 435-467. ISSN 1390-9304

A Novel Technique for Multiple Microgrids Planning by Considering Demand Response Programming and Social Welfare Enhancement in Power Market

Ali Menshari[1], Gholamreza Salehi[1]*, Mohammad Ghiamy[1]

1 Islamic Azad University, Tehran, Iran, rezasalehi20@gmail.com

ABSTRACT

This paper presents a novel approach for planning and operating of multiple Micro-grids in restructured power systems environment and electricity market. Power quality indicators, voltage profiles, and power losses are considered as effective parameters for supplying the network active and reactive powers. Also, the necessary financial incentives are introduced in this paper from the economic point of view for these resources, and demand response programs are also used. in which variables are programmable distributed generators and interruptible loads based on demand response programs. In the proposed model, the operator implements a market with the locational pricing and considering the power losses based on domestic market implementation and upstream market modeling in the role of a dual player. In this way, active and reactive power markets will implement simultaneously in order to maximize social welfare. Subsequently, the Beta and Weibull Probability Density Function (PDF) methods are used for modeling the uncertainties in power generation. Also, the Locational Marginal Pricing method (LMP) is used to determine the prices in the system and the intelligent GA-PSO hybrid algorithm is used for optimization of this problem. Finally, the results are compared with the results obtained from other algorithms.

Keywords: multiple microgrids; load response; reactive power market; renewable distributed generation resources; GA-PSO algorithm.

Received 03/04/2018
Approved 10/06/2018

1. INTRODUCTION

A power microgrid is a set of loads and distributed generation (DG) resources that has the ability to connect to the upward network and operate autonomously in island mode. In island mode, the power microgrid is separated from the upstream network and can supply its existing loads. Some of the advantages of operating in the Islanding mode are increased reliability, increased power quality and more flexibility. This has encouraged companies producing electricity in recent years to increase the quality of their supplied electricity by operating distribution networks in Islanding mode (during fault occurrence or predefined outage). Since it's no good disconnecting DG resources during fault occurrence or predefined outage, the microgrid operation is expected to be an appropriate option.

In this paper an algorithm is proposed for planning of multiple microgrids in exchange with the energy market considering reactive power.

In [1], a new method has been proposed to measure Battery Energy Storage System (BESS) by considering dynamic demand response (DR) and using Particle Swarm Optimization (PSO). In that article, the optimal size of BESS has been calculated based on frequency control of microgrid and through involving DR by PSO. The results have showed that compared to the optimal size of BESS based on Simulated Annealing (SA) with DR, the optimal size of BESS based on PSO with DR can lead to increased efficiency and create a rapid, faultless, immune and stable dynamic system. By the way, the proposed method has determined the effects of the costs related to BESS between modern and common BESS technologies. Then, the investment, operation and maintenance costs of BESS have been studied and compared to each other in terms of economy and microgrids' performances. In [2], load shift techniques have been used by dividing loads into two groups, high priority loads (HPL) and low priority loads (LPL). The HPLs must be supplied regardless of generation situation but the LPLs can be supplied when the renewable resources are available. That article introduces a new design and optimization to size the individual systems of the hybrid energy--photovoltaic(PV)/ wind/ diesel/ battery—techno-economically based on the smart-grid theory to generate energy with minimum cost and maximum reliability. Finally, an accurate method has been proposed

Received 03/04/2018
Approved 10/06/2018

to merge five sites of Saudi Arabia and ten wind turbines from different makers to maximize generated energy and minimize the cost of generated kWh.

In reference [3], a new strategy is provided for users of a low voltage Micro-grid for distributed and automated management of power on demand side. The main procedures for implementing this method are: a) Modeling energy consumption scheduling of time-shiftable loads belonging to a specific user is as a player of a two-player game with incomplete information in which the user himself/herself plays against the opponent that collects other users of the Micro-grid; (b) It is assumed that each user has statistical information about his or her behavior and the opponent, so he/she can select the behaviors that maximize his/her expected output.

In [4], the authors focused on two main objectives: (1) understanding the concept of how to assess the risks in smart grids, and (2) providing a more comprehensive view of risk in smart grids. In this paper, a CBA methodology was proposed and used as a basis for developing an elaborate list of criteria that includes dependency, interdependence, and flexibility, as well as accepted risk factors (ie, probabilities and consequences). This aggregation of factors can be used in a general analysis of smart grids. The CBA requirements and further research paths are also outlined in this article for realizing better capabilities in the smart grid.

In [5], three models for prediction are briefly presented: the regression model of support vector with three-day training, Support Vector Regression with optimized parameters by Genetic Algorithm (SVRGA) and the same model using Particle Swarm Optimization (SVRPSO). Unlike existing models, these models have a precise prediction by optimizing the regular structure risk function. These models use hourly load data from three previous days to predict the hourly load of the next day. This paper presents a comparative study between GA and PSO on the hyperparameter tuning of the SVR model.

In [6], the authors show that auxiliary services can manage energy by using renewable energy, stored energy and local generation (on-site generation) to reduce the expensive and high-cost power generation in the main network and satisfy the surplus demand of smart grid customers. A fractional integral is used to calculate the area under the curve, in order to compute the power consumption at a scheduled time equal to 15 minutes per

Received 03/04/2018
Approved 10/06/2018

hour, and the determination of demand levels. Also, the dynamic game model is used to dispatch the available distributed generation in order to satisfy customers' surplus demand. The results show that for a compilation program, the proposed method can reduce demand from the main grid and increase the flexibility of the system to activate the ready-to-use distributed generation.

In [7], a new Demand-Side Management (DSM) plan is suggested for automated DC Micro-grid in future buildings. The proposed control algorithm shifts lagging loads from non-sunny hours to sunshine hours and reduces building demand during non-sunny hours. This reduces battery charging/discharging cycles. By doing so, the power drop in the battery is reduced and the system's performance is upgraded. The proposed scheme reduces the size of the PV plant, storage cost, and system cost.

In [8], the planning of a microgrid has been done in the island and connected-to-the-network modes in presence of renewable DG resources including solar, wind, and storage systems. In that article, the presence of battery storage systems leads to the reduced disadvantages of the uncertainties related to power generation by DG resources and increased benefits of microgrid. Furthermore, the grey wolf search algorithm has been employed in that article.

In [9], a new method has been proposed for corrective voltage control (CVC) of power systems in the presence of uncertainties related to wind power generation and demand levels. In that article, the uncertainties related to wind power generation and demand levels are managed using a scenario-based method. A feature of the proposed method is use of demand-side resources as an effective control tool to reduce control costs. Active and reactive re-dispatching of generation units, mandatory load reduction and also demand-side voluntary participation (demand response) have been used as control tools in the proposed CVC method. Meanwhile, the CVC has been simulated as a multi-objective optimization problem. The considered objectives ensure desired loading margin while minimizing control costs. The problem has been resolved using constraint ε method and fuzzy satisfaction method has been used to select the best solution from the optimum set of Pareto responses. In [10], a modern multi-objective model (SMP-OPF) has been presented to optimize the design of a power grid that is connected to a wind farm by a

Received 03/04/2018
Approved 10/06/2018

huge HVDC converter. The used wind turbines in the study are Dual Fed Induction Generators (DFIGs) and their DFIG curves are used to obtain the accurate amount of the generated power of these turbines. In addition, the uncertainties caused by wind turbines' generation have been considered in the study. The problem has been tested on 118-bus IEEE test system to show the performance of the proposed model to obtain the optimum plan of active and reactive powers for heat and wind generation units. Finally, the obtained results show the ability of the proposed SMP-OPF model to determine the optimum performance of power systems.

In [11], a long-term simulation model has been employed to study the long-term dynamics of two specific policies which are used by policy-makers now. The first policy deals with correcting side effects by controlling CO_2 price in a level equal to the social cost of CO_2 emissions. Authors in [12] have studied if there had been a relationship between demand market balance and renewable energy resources in day-ahead electricity market of Italy from 2010 to 2011—the study has been done using individual prediction-based bids. Authors in [13] have focused on demand response and smart measurement for small and medium consumers to see what kind of market signals should be sent to demand managers in order to consider the demand response as a competitive activity.

Authors in [14] have focused on studying and determining the effect of different demand response models' costs on unit commitment and power distribution in day-ahead market. In the study, unit commitment model has been employed with mixed integer programming in the context of market operations. In [15], a new method has been presented for the determination, analysis and comparative assessment of the restrictions that today impede high demand response implementation. Authors in [16] have discussed the available strategies of effective risk management for retail electricity providers (REP) to work on the uncertainties of day-ahead market; they have also discussed how to prevent financial losses in the market.

In [17], the linear and nonlinear models of incentive-based demand response (IBDR) and price-based demand response (PBDR) has been presented and implemented in several real power markets. In the study, the results of implementing DR plans in electricity markets have been studied for different levels of reflexive load participation in DR plans.

Received 03/04/2018
Approved 10/06/2018

Authors in [18] studied the variations of the pre-registered load patterns of Korean commercial and industrial electricity consumers and their effects on daily-event loads during pricing experiment of critical peak in winter 2013.

In [19], real-time electricity markets have been divided into three groups: group 1 uses node prices implemented by optimal power flow that defray energy prices every 5 minutes; Group 2 uses regional prices with time resolution of 5 minutes. In [20], the business models have been studied and analysed in different parts of electricity market for energy efficiency (EE) and DR providers. The analysis covers three characteristics: demand-side management (DSM) exchange characteristic, renewable energy correlation and characteristic of DSM’s load control.

The effect of demand elasticity on electricity market has been studied in [21]. The extended model of Kornovet has been extracted from classic model of Kornovet by taking into account the demand elasticity. The results of simulations show that the demand elasticity can effectively impress market outputs namely market clearing price (MCP), load payment and the output and individual benefit of production companies. In [22], the platforms of game theory have been presented for demand response in electricity market and consumer levels. First the interaction between demand response aggregator (DRA) and electric generators has been modelled as Stackelberg game in which DRA (as game leader) create demand reduction tenders and generators (as followers) compete to maximize their benefit based on reduced demand.

In [23], we study the effect of dynamic demand response on future smart grid abstractly to analyse the trade-off between efficiency and risk under different architectures of market. First we study the performance of system under participatory and non-participatory architectures of market. A set of robust mixed integer linear programming problems must be resolved in [24]. Instead of using predicted prices as inputs, the upper and lower limits of pool prices are considered to model uncertainty.

In this article, the planning of multiple microgrids is done by using GA-PSO algorithm in the presence of renewable DG resources and load response in a competitive electricity market environment. In the model proposed in the research it is assumed that DG units are able to participate in wholesale market and their location is accomplished based on

Received 03/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 435-467. ISSN 1390-9304

the margin local price of electricity. The amount of subscribers' payments in each bus that is equal to the product of local marginal price and power amount of that bus is used as an index to rank selected points for installation of DG units.

In the following of this paper, at first, the modeling of loads and distributed generation resources and the process of market clearing is presented and then, the general model of the system for planning of multiple microgrids in exchange with the energy market and considering reactive power and related constraints are presented. After that, the optimization algorithm and numerical studies are expressed and in the final section, the conclusions of the study are presented.

1.1. Modelling loads and DGs

The appropriate modelling of DGs and loads is completely necessary to design optimal microgrids in a distribution system. For this purpose, a combination of two conventional DG technologies namely PV modules and wind turbines has been studied in this study. According to the unpredictable nature of PV and wind renewable resources, the solar radiation and wind speed in each hour of day have been modelled with Beta and Weibull probability density functions (PDFs) respectively—the experimental data has been used for this purpose [25]. In this design, each day is divided into 24 parts so that each part has a PDF for solar radiation and wind speed. In addition, load has been modelled hourly using IEEE-RTS. To embed output power of PV modules and wind turbines as multi-state variables in formulations, the continuous PDFs of theirs are divided into different states. The number of selected states impresses the accuracy and complication of formulation. In this research, the output power of PV modules and wind turbines has been divided into four parts for each hour of day that each of them (the parts) has different probability. Assuming the states of solar radiation and PV modules are independent of each other, the probability related to each combination of loads and generation is determined by combining the two probabilities. So there will be 16 (4*4), 384 (16*24) and 140,160 (365*384) states with different probabilities for each hour, day and year respectively that include different timescales (day and night) with different penetration levels of DGs.

Received 03/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 435-467. ISSN 1390-9304

The operator of this domestic market is the operator of multiple microgrid that in addition to immune operation of grid, handle the planning with the aim of satisfying all actors. Here it is assumed that the domestic market of multiple microgrid is an hour-ahead market that the generation resources of multiple microgrid declare their power generation offers in a set of generation steps with determined prices in each hour. In addition, RTP method is used for load response that is a real-time load response method.

If the multiple microgrid to be considered as connected to upstream network (in most hours), then the operator of microgrid must perform a plan to find optimal combination by considering the capacity and price of connection to upstream network and necessity of supplying uninterruptable loads. The economic exchange process of this domestic market can be modelled as a centralized market with uniform local pricing [21] in which DGs price in ascending order and uninterruptable loads in descending order based on their needs. Market clearing price is achieved at the intersection of the highest price of generators and that of consumers.

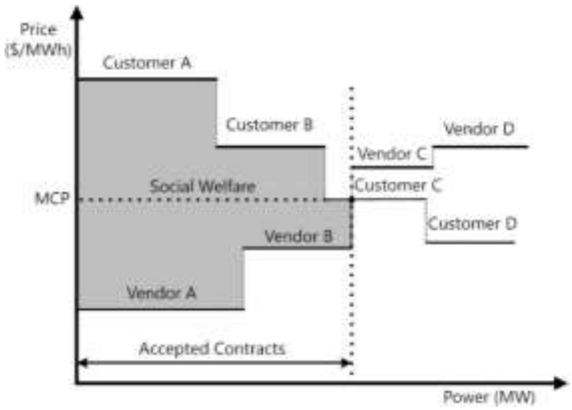

Figure 1. Market clearing process.

2. PROBLEM MODELLING

2.1. Microgrid planning in exchange with energy market and reactive power

In this section, the planning of multiple microgrid is modelled for exchange with market energy and reactive power. The objective function can be defined as maximization of a

Received 03/04/2018
Approved 10/06/2018

social welfare function resulted from simultaneous purchase and sale of active and reactive power to domestic markets and exchange with upstream network and other microgrids in a power quality improvement reserve.

It is assumed that microgrid should profit (if it can) from reactive power sale to—or exchange that with—upstream network or other microgrids while covering its reactive power costs. In this article, the objective function maximizes profit and power quality. Our objective function is modelled by considering the reactive power generation cost of DG units as well as the sale price of load for reactive power and exchange with upstream network.

$$\text{Minimize}\, F_{total} = \text{Minimize}\{F_{SS.n}, F_{PQ.n}\} \tag{1}$$

$$F_{SS.n} = \frac{F_{SS.b}}{Gs - Ex}$$

$$Gs = \sum_{t=1}^{24} \left(\begin{array}{l} \sum_{i=1}^{N_{NU}} \left(P_{i,t}^{NU} \times \pi_{\beta,t} \right) + \sum_{i=1}^{N_{DU}} \left(P_{i,t}^{DU} \times \pi_{\beta,t} \right) + \left(P_i \times \pi_{\beta,t} \right) \\ + \sum_{i=1}^{N_{NU}} \left(q_{i,t}^{NU} \times \pi_{\beta Q,t} \right) + \sum_{i=1}^{N_{DU}} \left(q_{i,t}^{DU} \times \pi_{\beta Q,t} \right) + \left(Q_i \times \pi_{\beta Q,t} \right) \end{array} \right) \tag{2}$$

$$Ex = \sum_{t=1}^{24} \left(\begin{array}{l} \sum_{i=1}^{N_{NU}} C_i^{NU} \left(P_{i,t}^{NU} \right) + \sum_{i=1}^{N_{DU}} C_i^{DU} \left(P_{i,t}^{DU} \right) + \sum_{i=1}^{N_{CL}} C_i^{CL} \left(P_{i,t}^{CL} \right) + \left(P_i \times \pi_{A,t} \right) \\ + \sum_{i=1}^{N_{NU}} C_{Q,i}^{NU} \left(q_{i,t}^{NU} \right) + \sum_{i=1}^{N_{DU}} C_{Q,i}^{DU} \left(q_{i,t}^{DU} \right) + \left(Q_i \times \pi_{AQ,t} \right) \\ + \sum_{i=1}^{N_{DU}} SC_i \times \left(1 - I_{i,t-1} \right) + P_{Loss} \times \pi_{A,t} + Q_{Loss} \times \pi_{AQ,t} \end{array} \right) \tag{3}$$

$$\begin{array}{l} F_{SS} = \sum_{t=1}^{24} \Big(\sum_{i=1}^{N_{NU}} \left(P_{i,t}^{NU} \times \pi_{\beta,t} \right) + \sum_{i=1}^{N_{DU}} \left(P_{i,t}^{DU} \times \pi_{\beta,t} \right) + \sum_{i=1}^{N_{NU}} \left(q_{i,t}^{NU} \times \pi_{\beta Q,t} \right) + \sum_{i=1}^{N_{DU}} \left(q_{i,t}^{DU} \times \pi_{\beta Q,t} \right) \\ - \sum_{i=1}^{N_{NU}} C_i^{NU} \left(P_{i,t}^{NU} \right) + \sum_{i=1}^{N_{DU}} C_i^{DU} \left(P_{i,t}^{DU} \right) - \sum_{i=1}^{N_{CL}} C_i^{CL} \left(P_{i,t}^{CL} \right) - \sum_{i=1}^{N_{NU}} C_{Q,i}^{NU} \left(q_{i,t}^{NU} \right) - \sum_{i=1}^{N_{DU}} C_{Q,i}^{DU} \left(q_{i,t}^{DU} \right) + \\ \left(P_i \times (\pi_{B,t} - \pi_{A,t}) \right) + \left(Q_i \times (\pi_{BQ,t} - \pi_{AQ,t}) \right) - \sum_{i=1}^{N_{DU}} SC_i \times \left(1 - I_{i,t-1} \right) - P_{Loss} \times \pi_{A,t} - Q_{Loss} \times \pi_{AQ,t} \Big) \end{array} \tag{4}$$

Where:

FSS_n: the base value of social welfare function;

Received 03/04/2018
Approved 10/06/2018

$P_{i,t}^{DU}$: the active power of i^{th} programmable unit at hour t (kW);

$P_{i,t}^{NU}$: the active power of i^{th} unprogrammable unit at hour t (kW);

$q_{i,t}^{DU}$: the reactive power of i^{th} programmable unit at hour t (kVAR);

$q_{i,t}^{NU}$: the reactive power of i^{th} unprogrammable unit at hour t (kVAR);

$P_{i,t}^{CL}$: the interrupted power of interruptible load i at hour t (kW);

P_t: the exchanged power with upstream network and other microgrids at hour t (kW);

$\tau_{A,t}$: the energy price in upstream market at hour t (currency/kWh);

$\tau_{B,t}$: the energy price in microgrid at hour t (currency/kWh);

C_i^{DU}: the cost function of programmable units (currency/h);

C_i^{NU}: the cost function of unprogrammable units (currency/h);

C_i^{CL}: the interruption cost of interruptible loads (currency/h);

SC_i : the start cost of DG units (currency/h);

$I_{i,t}$: binary variable that shows off/on state of unit at hour t;

$C_{Q,i}^{NU}$: the cost function of unprogrammable units' reactive power (currency/h);

$C_{Q,i}^{DU}$: the cost function of programmable units' reactive power (currency/h);

$\pi_{BQ,i}$: reactive power price in microgrid at hour t (currency/kVarh);

$\pi_{BQ,i}$: reactive power price in upstream market at hour t (currency/kVarh).

In above objective function the first and second terms show the income obtained from selling the energy that resulted from unprogrammable and programmable DG units respectively. The third and fourth terms show the power generation cost of DG units. The fifth term shows the cost of load interruption for interruptible loads, in fact it is the money that must be paid to loads in order to interrupt part of their load. The sixth term shows the income or cost resulted from exchanging power with upstream network.

P_t and Q_t are the active and reactive power of microgrid (respectively) that are exchanged with upstream network or other microgrids and are defined as a variable in a range of positive (in case of buying from upstream network) and negative (in case of selling to upstream network). Finally, the last term shows the start cost of DG units.

Received 03/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 435-467. ISSN 1390-9304

The cost function of each DG unit can be estimated from active power output by a second-order or first-order function. Usually, the cost function of programmable units is estimated by a second-order function and that of unprogrammable units (that their major cost is repair and maintenance cost) is estimated by a first-order function. α, β and γ are the coefficients of DG units' cost function.

$$C_i^{DU}(P_i^{DU}) = \alpha.P_i^{DU^2} + \beta.P_i^{DU} + \lambda \tag{5}$$

$$C_i^{NU}(P_i^{NU}) = \beta.P_i^{NU} + \lambda \tag{6}$$

Also, the interruption cost of interruptible loads can be defined as a polynomial function [60]. In this problem, this cost is represented as follows:

$$C_i^{CL}(P_i^{CL}) = \alpha.P_i^{CL^2} + \beta.P_i^{CL} + \lambda \tag{7}$$

The cost function of reactive power for programmable DG resources is modelled by a second-order function.

$$C_{Q,i}^{DU}(Q_i^{DU}) = \alpha.Q_i^{DU^2} + \beta.\mathrm{Q}_i^{DU} + \lambda \tag{8}$$

Also, the cost function of reactive power for unprogrammable DG resources is defined as a linear function in a certain power factor.

$$C_{Q,i}^{NU}(Q_i^{NU}) = \beta.Q_i^{NU} + \lambda \tag{9}$$

This objective function attempts to maximize the profit resulted from exchange of active and reactive powers by taking into account the constraints and the dependence between active and reactive powers. According to the structure of objective function, the simultaneous optimization of active and reactive powers is necessary.

Also, the objective function of power quality is defined as follows (that is the revers of the proportion of voltage difference between buses to reference voltage).

$$Min\ K_{P.V} = \sum_{i=1}^{n_f} |V_{ref} - V_i| \tag{10}$$

This part of objective function shows the voltage distortion of different buses from their reference value. In fact, it shows their voltage drop in network and our main goal in this part of function is minimization of this voltage drop.

Received 03/04/2018
Approved 10/06/2018

$$F_{PQ.n} = \frac{K_{p.v}}{K_{bprof}} \quad (11)$$

$K_{p.v}$: the base voltage drop of profile;

K_{bprof}: the maximum possible voltage drop in system;

$K_{n.p.v}$: the normalized value of voltage profile;

V_{ref}: the reference voltage;

V_i: the voltage of bus i.

2.2. The general objective function

The general objective function that is equal to the total normalized values of all objective functions by considering the weight factor of each function and is determined as follows:

$$\text{Minimize} \quad F_{total} = K_1 * F_{SS.n} + K_2 * F_{PQ.n} \quad (12)$$

Where K_1 is the weight factor related to the social welfare function and K_2 is the weight factor related to the power quality function.

2.3. Problem constraints

The constraints of problem are modelled as follows (for 24-hour operation):

2.3.1 The constraint of generation and load balance

In every hour, the amounts of generation and load for the active power of microgrid must be equal. In the following equations, $q_{i,t}^{NU}$ and $q_{i,t}^{DU}$ are the reactive power of programmable and unprogrammable units respectively. In addition, $Load_t$ and $Loss_t$ are the active load of microgrid and the losses of active power respectively.

$$\sum_{i=1}^{N_{DU}} \left(P_{i,t}^{NU}\right) + \sum_{i=1}^{N_{DU}} \left(P_{i,t}^{DU}\right) + \sum_{i=1}^{N_{CL}} \left(P_{i,t}^{CL}\right) + P_t = P_{loadt} + P_{Losst} \quad (13)$$

2.3.2 The constraint of minimum required reserve

Received 03/04/2018
Approved 10/06/2018

The operator of microgrid should guarantee a required reserve margin in each hour by considering on units and exchange with network. $Rest$ is the required reserve of microgrid, as an example, $Rest$ is considered as 10 percentage of microgrid load.
$P_{i,Max}^{DU}$, $P_{i,Max}^{NU}$, and $P_{Max,t}$ are maximum generated power of DG units, maximum interrupted load of interruptible loads, and maximum exchange with upstream network respectively.

$$\sum_{i=1}^{N_{DU}}\left(P_{Maxi,t}^{DU}-P_{i,t}^{DU}\right).I_{i,t}+\sum_{i=1}^{N_{CL}}\left(P_{Maxi,t}^{CL}-P_{i,t}^{CL}\right).I_{i,t}+(P_{Max,t}-P_t)\geq \mathrm{Re}\,s_t \quad (14)$$

The reserve for reactive power is defined similarly that is presented in following equation:

$$\sum_{i=1}^{N_{DU}}\left(Q_{Maxi,t}^{DU}-Q_{i,t}^{DU}\right).I_{i,t}+(Q_{Max,t}-Q_t)\geq \mathrm{Re}\,s_{Q,t} \quad (15)$$

2.3.3 The constraints of units' generation limits

$$P_{dg}<P_{dg\max} \quad (16)$$

$$Q_{dg}<Q_{dg\max} \quad (17)$$

2.3.4 The constraints of minimum active and pause time of micro-turbine units

In these equations $T_{i,t}^{on}$ and $T_{i,t}^{off}$ are continuous on time and off time of i^{th} unit until hour t respectively and MU_i and MD_i are minimum active and pause time of i^{th} unit.

$$(1-I_{i,t}).MU_i\leq T_{i,t}^{on} \qquad if\ \ I_{i,t-1}=1 \quad (18)$$

$$I_{i,t}.MD_i\leq T_{i,t}^{off} \qquad if\ \ I_{i,t-1}=0 \quad (19)$$

2.3.5 The constraints of the increasing and decreasing slopes of micro-turbine units

In the following relations, $\mathrm{RUP}_\mathrm{i}^\mathrm{DU}$ and $\mathrm{RDN}_\mathrm{i}^\mathrm{DU}$are increasing and decreasing slopes of unit i:

$$P_{i,t+1}^{DU}-P_{i,t}^{DU}\leq RUP_i^{DU} \qquad if\ the\,output\,is\,increased \quad (20)$$

$$P_{i,t}^{DU}-P_{i,t+1}^{DU}\leq RDN_i^{DU} \qquad if\ the\,output\,is\,decreased \quad (21)$$

Received 03/04/2018
Approved 10/06/2018

$$Q_{i,t+1}^{DU} - Q_{i,t}^{DU} \leq RUQ_{i}^{DU} \quad \text{if the output is increased} \tag{22}$$

$$Q_{i,t}^{DU} - Q_{i,t+1}^{DU} \leq RDN_{i,Q}^{DU} \quad \text{if the output is decreased} \tag{23}$$

$$0 \leq P_{i,t}^{CL} \leq P_{Maxi,t}^{CL} \tag{24}$$

$$\left| P_t \right| \leq P_{Max,t} \tag{25}$$

$$\left| Q_t \right| \leq Q_{Max,t} \tag{26}$$

2.3.6 The constraints of the maximum interruptible load and exchangeable power with the upstream network

$P_{Max,i,t}^{DU}$ is the maximum interruptible power of i^{th} load. Microgrid contracts with interruptible loads to interrupt their loads (if needed) in certain hours up to declared maximum by load. Also, $P_{Max,t}$ is maximum exchanged power with upstream network that must be considered to plan generation in each hour.

$$0 \leq P_{i,t}^{CL} \leq P_{Maxi,t}^{CL} \tag{27}$$

$$\left| P_t \right| \leq P_{Max,t} \tag{28}$$

$$\left| Q_t \right| \leq Q_{Max,t} \tag{29}$$

2.3.7 Security constraints of microgrid

The microgrid's operator must make sure that the microgrid is secure during planning. For this purpose, he/she considers the constraints of lines' maximum powers and buses' voltage limits. In the following equations, V_i^{Max} *and* V_i^{Min} are upper and lower limits of allowed voltage for buses. In addition, $S_{i,j,t}$ is the transformed power through each line connected to bus i and $S_{i,j}^{Max}$ is the allowed loading limit of line.

$$V_i^{Min} \leq V_{i,t} \leq V_i^{Max} \tag{30}$$

$$S_{i-j,t} \leq S_{i-j}^{Max} \tag{31}$$

Received 03/04/2018
Approved 10/06/2018

2.3.8 The constraint of minimum power factor for connection to upstream network

It is assumed that the network's operator has agreed with microgrid's operator to satisfy the constraint of load connection with a certain power factor when the microgrid is drawing active and reactive power, in other words when it has load role for upstream network.

So the exchanged power with upstream network can be limited by following constraint in which μ is minimum allowed power factor for connection to upstream network and $\cos\varphi t$ is the power factor of connecting to upstream network when the microgrid has load role.

$$COS\,\varphi_t \geq \mu \qquad if \quad P_t, Q_t \rangle 0 \tag{32}$$

3. GA-PSO ALGORITHM

The implementation process of algorithm GA-PSO is as follows:

- First, we select a population randomly that are GA components and PSO particles actually.
- The fitness of components is calculated.
- Half the population that have higher fitness are selected and PSO operations are applied to them. However this factor is named Breeding Ratio (ψ) this factor determines that what percentage of the population are placed under PSO operations. If the total population be N, then the algorithm selects $\psi.N$ particles with higher fitness to create enhanced elites by applying PSO calculations to them. This way, PSO particles are adapted with problem's conditions and their environment more and more that this process is similar to the growth of creatures in nature.
- The enhanced elites are transformed to the next generation directly and the rest of population are created by applying mutation and crossover operations to them.

The following figure represents all of the above-mentioned steps.

Received 03/04/2018
Approved 10/06/2018

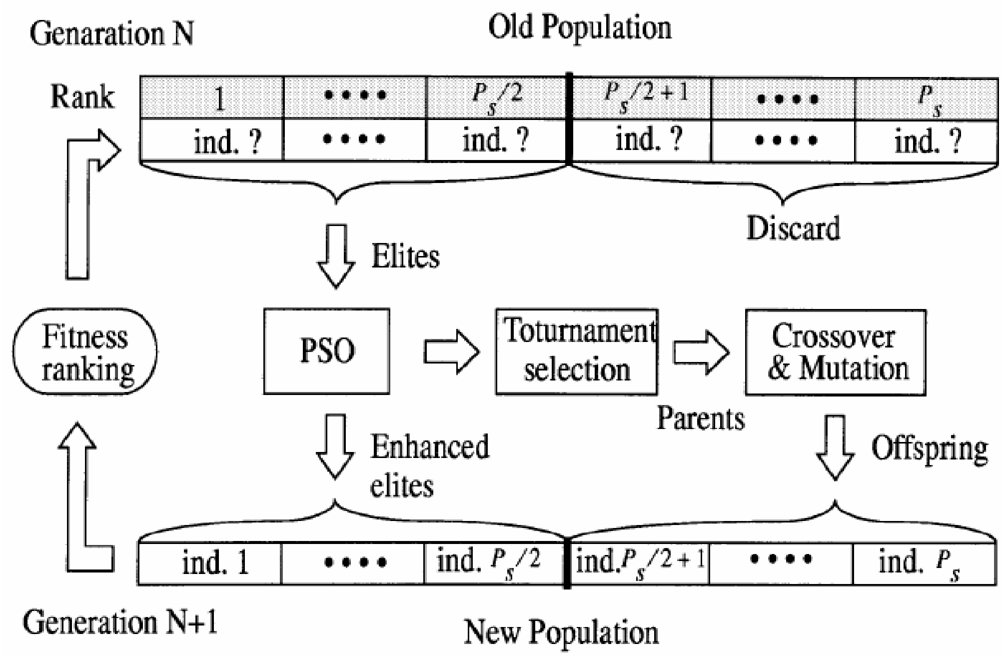

Figure 2. The implementation steps of GA-PSO algorithm [7].

4. NUMERICAL STUDIES

The under-study system is a low-voltage network that contains three microgrids and different types of domestic, commercial and industrial loads. In this network, different types of DGs namely 7 wind turbines, 3 micro-turbines, 8 photovoltaic cells and 3 reactive power source have been used. In addition, some of the required load is supplied by upstream network that is electrical energy market here.

In this system, the multi-objective optimal operation of microgrid is done in the presence of demand response. It is assumed that all the DGs work in power factor 1.0 and don't generate or absorb any reactive power. The cost of purchased energy from wind and solar units is equal to their operation cost and is considered zero.

It is assumed that the micro-turbines work with natural gas and efficiency of 8.8 kWh/m^3. Fuel price is considered as 0.8 $\$/L$ [18]. The efficiency of micro-turbine to consume natural gas is assumed equal to 26%.

For units consuming fuel, this cost is uniformly distributed on their working hours. It is assumed that MT work in 90% of the year (or in 1884 hours). For standard-based DGs,

Received 03/04/2018
Approved 10/06/2018

the annual cost is calculated based on their generations. Therefore, each generated kWh by those resources must be assessed against installation and depreciation costs.

In this article, we consider some different states to achieve the best possible solution on the sample network so that the problem of planning microgrid (from the perspective of the electricity market) is resolved to achieve maximum social welfare and power quality—as mentioned earlier.

In Fig. 4 the load curves of each supplier resource and whole microgrid have been represented for a normal work day of the year. The total required energy for this day is $2616\ kWh$. It is assumed that the power factors of all loads are equal to 0.85 (lagging). The resistances and reactances of lines are listed in Table 1. In this section, the steps of problem simulation are done using software MATLAB and algorithm PSO-TVAC and the results are discussed.

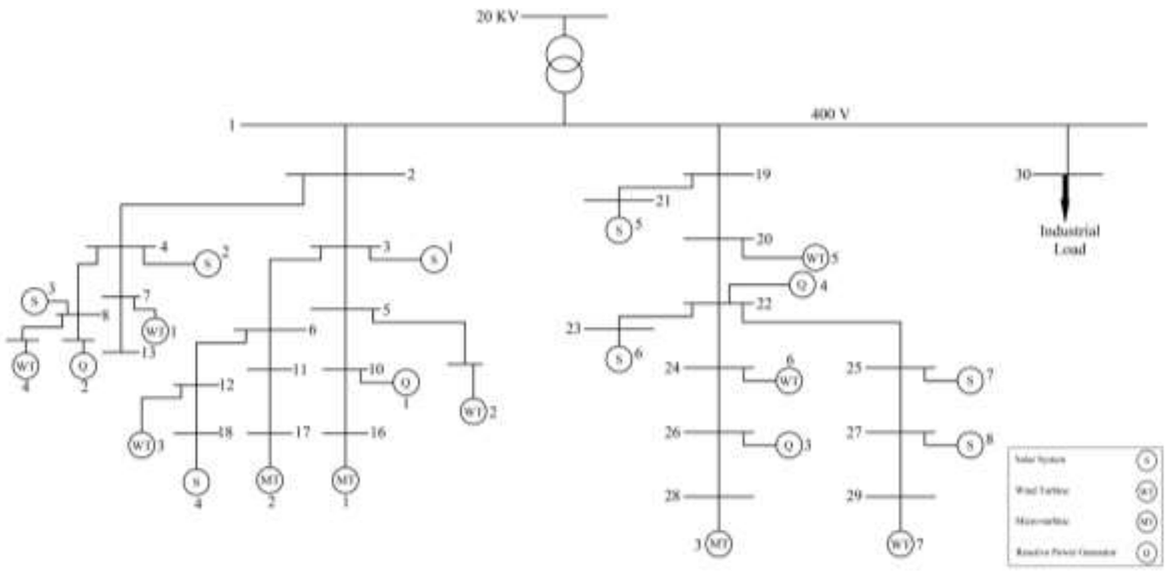

Figure 3. Studied micro grid.

Received 03/04/2018
Approved 10/06/2018

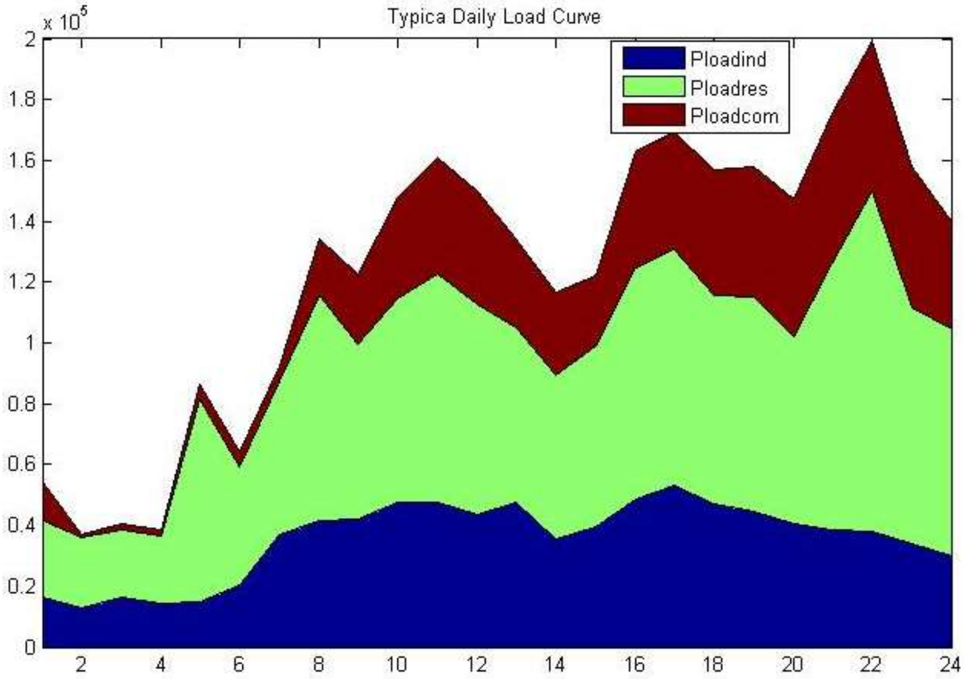

Figure 4. the common load curve for each supplier of studied network.

The values of lines' $R\ and\ X$ are calculated by base power of $100\ kVA$ and base voltage of $400\ V$. It should be noted that start cost is only considered for fuel-consuming units. To calculate the start cost of MT, the fuel cost in start time at full capacity and half efficiency is inserted to calculations.

Table 1. The studied network lines data.

Origin bus	**Destination bus**	$\boldsymbol{R(pu)}$	$\boldsymbol{X(pu)}$	**Origin bus**	**Destination bus**	$\boldsymbol{R(pu)}$	$\boldsymbol{X(pu)}$
2	1	10.152	0.1756i	15	8	15.228	0.2633i
19	1	11.421	0.1975i	16	10	5.076	0.0878i
30	1	15.228	0.2633i	17	11	10.152	0.1756i
3	2	13.959	0.2414i	18	12	8.883	0.1536i
4	2	9.8982	0.1712i	20	19	12.4362	0.2151i
5	3	9.5175	0.1646i	21	19	8.6292	0.1492i
6	3	6.345	0.1097i	22	20	10.2789	0.1778i
7	4	11.421	0.1975i	23	22	9.0099	0.1558i

Received 03/04/2018
Approved 10/06/2018

8	4	15.228	0.2633i	24	22	3.2994	0.0571i
9	5	16.497	0.2853i	25	22	6.2181	0.1075i
10	5	6.345	0.1097i	26	24	19.035	0.3292i
11	6	11.421	0.1975i	27	25	15.228	0.2633i
12	6	8.883	0.1536i	28	26	5.076	0.0878i
13	7	6.345	0.1097i	29	27	12.0555	0.2085i
14	8	12.69	0.2195i				

Table 2 shows the maximum and minimum functional limits of DG resources. The minimum technical performance of MT has been obtained from the experimental results of [13] and hence its performance will be sustainable in continuous operation. In addition, its maximum start time is slightly more than 2 minutes that is clearly less than selected 15-minute time-step [13].

Table 3 shows the factors of assumed cost for DG resources in $ and for each kWh and h. In this table, start costs are also listed, if possible. Furthermore, to simplify the analysis, it is assumed that all the units only work in electric mode and there is no need to heat in studied period. As it is observed, in addition to obtained DGs, a micro-turbine has been added to the system in the first system.

Table 2. Installed DG resources.

Unit number	**Minimum power (kW)**	**Maximum power (kW)**	**Unit number**	**Minimum power (kW)**	**Maximum power (kW)**
MT1	6	20	PV6	0	2
MT2	6	20	PV7	0	3
MT3	6	30	PV8	0	1.5
QG1	5	20	WT1	0	1.5
QG2	4	15	WT 2	0	1.5
QG3	5	20	WT 3	0	1
PV1	0	1	WT 4	0	1.4
PV2	0	2.5	WT 5	0	1

Received 03/04/2018
Approved 10/06/2018

PV3	0	1.5	WT 6	0	3
PV4	0	1.5	WT 7	0	2.5
PV5	0	1			

As it can be seen in the table, the capacity of solar and wind resources are the previous capacities and two microgrid has been added to network in this state and has been installed in different sections of the system. Also, the solar panels that are mostly rooftop have been used here.

Table 3. The costs of DG units.

Unit type	$b_i(\$/kWh)$	$c_i(\$/h)$	**Start cost in $**
MT1	4.37	85.06	9
MT2	2.84	255.18	9
MT3	2.84	225.18	9
QG1	1.68	70.03	7
QG2	1.43	54.23	7
QG3	1.68	70.03	7
PV1	54.84	0	0
PV2	54.84	0	0
PV3	54.84	0	0
PV4	54.84	0	0
PV5	54.84	0	0
PV6	54.84	0	0
PV7	54.84	0	0
PV8	54.84	0	0
WT1	10.63	0	0
WT 2	10.63	0	0
WT 3	10.63	0	0
WT 4	10.63	0	0

Received 03/04/2018
Approved 10/06/2018

WT 5	10.63	0	0
WT 6	10.63	0	0
WT 7	10.63	0	0

The proposed prices by each of the available generating resources in the microgrids, and the power exchange between them and the grid are summarized in Table (4).

Table 4. The proposed prices by each of the available generating resources in the microgrids, and the power exchange between them and the grid

Unit type	**Min cost ($/kwh)**	**Max cost ($/kwh)**
MT	0.14	0.16
QG	0.16	0.17
PV	0.08	0.11
WT	0.03	0.09
Buy from a micro-grid and sell it to another micro-grid	0.07	0.17
Buy from a micro-grid and sell it to grid	0.05	0.115
Buy from grid and sell it to micro-grid	0.16	0.18

a. Scenario 1

In this scenario that is the base state of the experiment, we operate system without considering the internal resources of microgrid and only by external resources. In this case, the total power requirement of system is supplied through global grid. In this condition, the different parts of study's objective function are as table 5.

Table 5. The results related to the first scenario.

The active power exchanged with global grid (kw)	2969.83
The reactive power exchanged with global grid (kvar)	1781.898

Received 03/04/2018
Approved 10/06/2018

Power losses (pu)	0.0021037
The value of system voltage profile function	113.577
Consumer surplus impurity ($)	228.0746
System operation cost ($)	0
The normalized value of social welfare function	0.526143
The normalized value of power quality function	0.9490
The value objective function	0.73762

In this case, the total required power of system is supplied by grid and this causes the grid to supply its loads with low power quality thus the value of social welfare function is not so good.

b. Scenario 2

In this scenario, the system is operated by considering multiple microgrids and renewable distributed generation resources like wind and solar resources which are the internal resources of microgrids. In this case, wind and solar resources and global grid supply system loads in parallel. Furthermore, we use LMP method that was presented in previous section to determine grid costs. In this case, the different parts of objective function are as table 6.

Table 6. The results related to the second scenario.

	MG 1	MG 2	MG 3
The power generated by solar resources (kw)	681.7472	745.0852	0
The power generated by wind resources (kw)	1961.472	1621.330	0
The power generated by micro-turbines (kw)	0	0	0
The power generated by reactive resources (kvar)	0	0	0
The power related to interruptible loads (kw)	0	0	0
The active power exchanged with global grid (kw)	2209.152		
The reactive power exchanged with global grid (kvar)	1781.898		

Received 03/04/2018
Approved 10/06/2018

Power losses (pu)	0.0039827
The value of system voltage profile function	117.8977
Consumer surplus impurity ($)	343.615
System operation cost ($)	0
The normalized value of welfare function	0.174614
The normalized value of power quality	0.9811
Objective function value	0.577859

How to operate the system at different hours of the day and by different resources and global grid is represented in figure 5. As it can be seen, the operation cost of system and thus the value of social welfare function and power quality of system have been improved. The voltage profile at peak hours has been showed in figure 6. As it can be seen the system voltage is in allowed range in this case.

Received 03/04/2018
Approved 10/06/2018

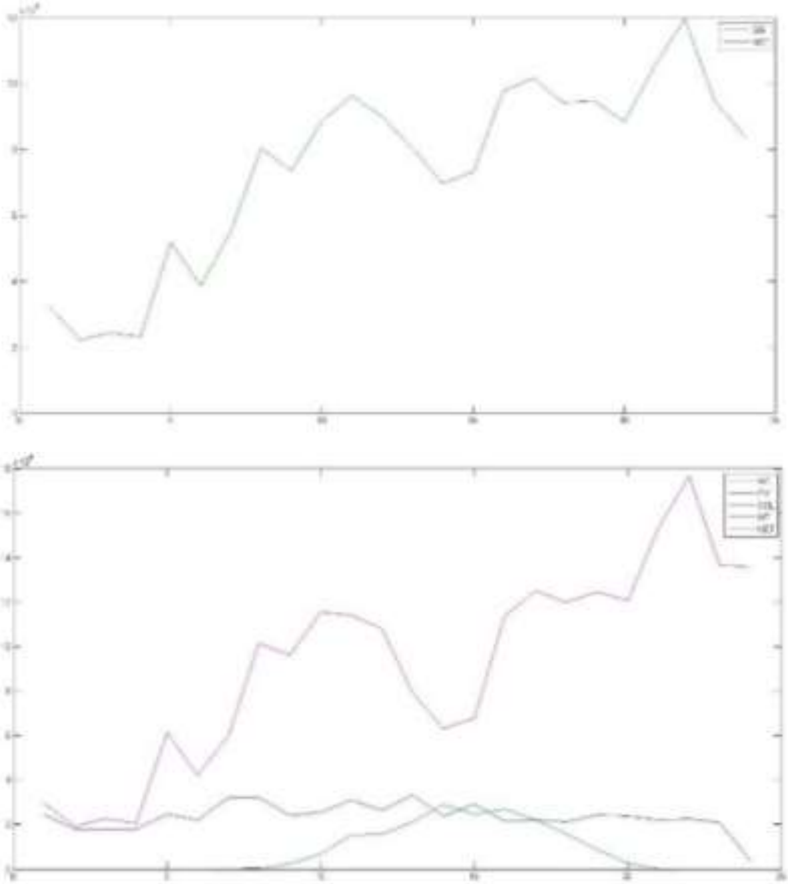

Figure 5. How to operate system resources at different hours of the day and by different resources in the second scenario.

Received 03/04/2018
Approved 10/06/2018

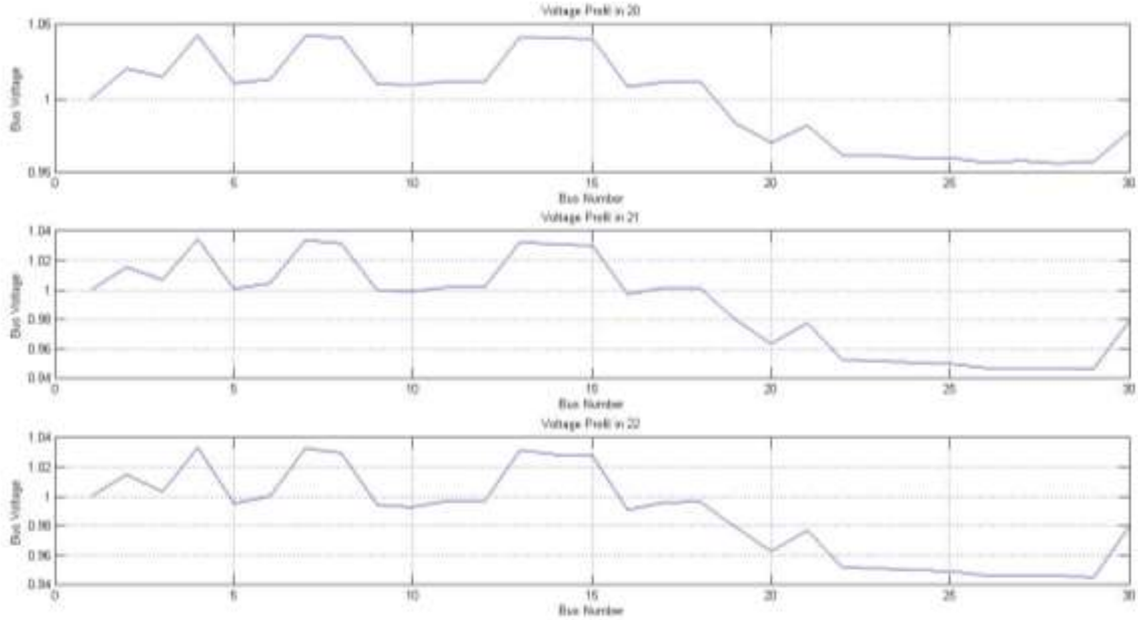

Figure 6. Voltage profile at peak hours (20, 21, and 22 O'clock respectively) in the second scenario.

c. Scenario 3

In this scenario, the system is operated by considering multiple microgrids, renewable distributed generation resources like wind and solar resources, and programmable distributed resources like micro-turbines and reactive power generation resources. In this case, reactive power market is created and microgrids can share their surplus reactive power with other microgrids. In addition, different pricing processes are performed under different scenarios. In this case, the different parts of the objective function are as table 7.

Table 7. The results related to the third scenario.

	MG 1	MG 2	MG 3
The power generated by solar resources (kw)	423.788	487.1268	0
The power generated by wind resources (kw)	1210.386	1058.015	0
The power generated by micro-turbines (kw)	1227.019	1079.515	0
The power generated by reactive resources (kvar)	313427	139411	0
The power related to interruptible loads (kw)	0	0	0

Received 03/04/2018
Approved 10/06/2018

The active power exchanged with global grid (kw)	1900.924
The reactive power exchanged with global grid (kvar)	1329.06
Power losses (pu)	0.002104466
The value of system voltage profile function	11.2458
Consumer surplus impurity ($)	541.0567
System operation cost ($)	404.977
The normalized value of welfare function	0.440919
The normalized value of power quality	0.52123
Objective function value	0.481074

How to operate the system at different hours of the day, and by different resources and global grid is represented in figure 7. As it can be seen, the operation cost of system and thus the value of social welfare function and power quality of system have been improved. The voltage profile at peak hours has been showed in figure 8. As it can be seen the system voltage is in allowed range in this case.

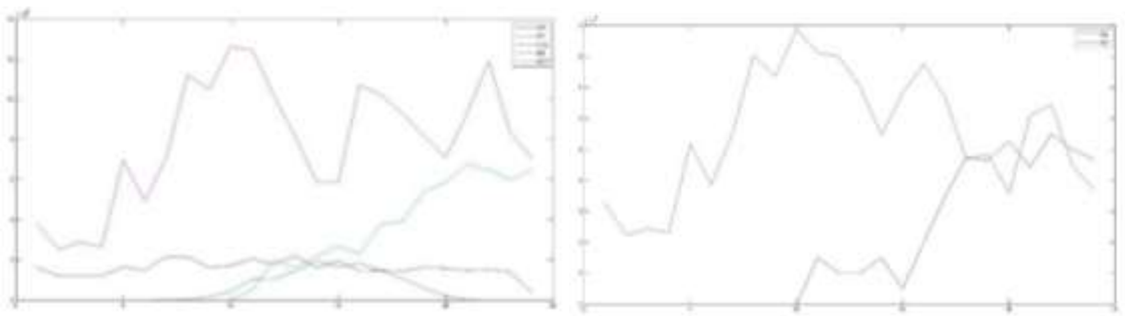

Figure 7. how to operate system resources at different hours of the day and by different resources in the third scenario.

Received 03/04/2018
Approved 10/06/2018

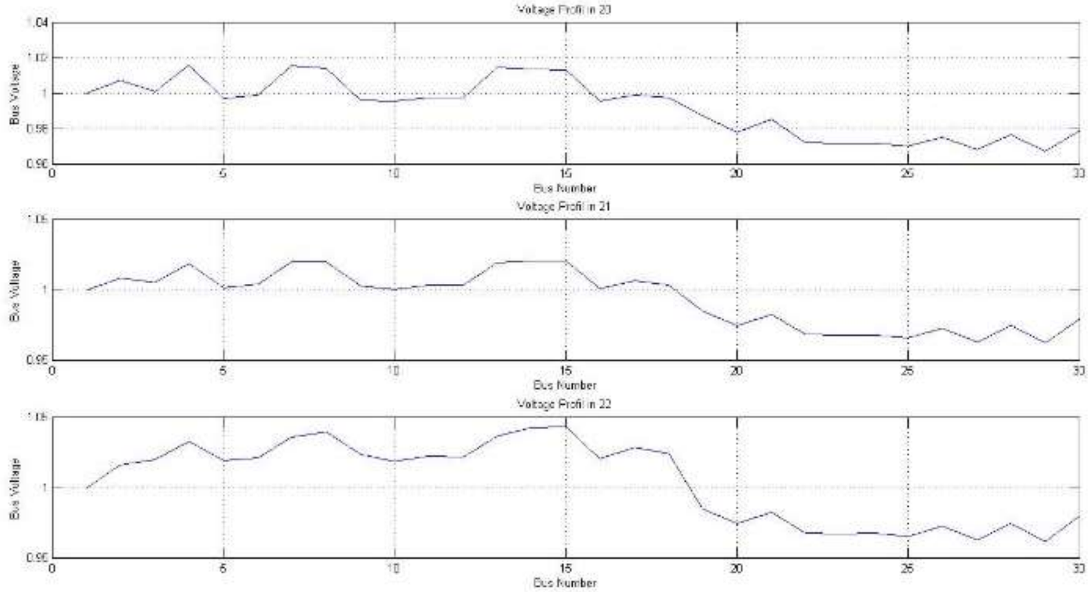

Figure 8. voltage profile at peak hours (20, 21, and 22 O'clock respectively) in the third scenario.

d. Scenario 4

In this scenario, we operate the system by considering multiple microgrids and all conditions of scenario 3. The possibility of load response by RTP method is considered too. In this article, the existing loads of system can participate in load response up to 20% of existing residential loads. In this case, the loads participating in load response are interruptible loads which are the non-sensitive loads of microgrids 1 and 2. In this case, the different parts of studied objective function are as table 8.

Table 8. The results related to the fourth scenario.

	MG 1	MG 2	MG 3
The power generated by solar resources (kw)	423.788	487.1268	0
The power generated by wind resources (kw)	1210.386	1058.015	0
The power generated by micro-turbines (kw)	1217.019	1069.843	0
The power generated by reactive resources (kvar)	296274	135215	0
The power related to interruptible loads (kw)	76.6883	0	0
The active power exchanged with global grid (kw)	1890.204		

Received 03/04/2018
Approved 10/06/2018

The reactive power exchanged with global grid (kvar)	1350.409
Power losses (pu)	0.00212738
The value of system voltage profile function	11.32028
Consumer surplus impurity ($)	541.4378
System operation cost ($)	401.5753
The normalized value of welfare function	0.42899
The normalized value of power quality	0.52255
Objective function value	0.47577

How to operate the system at different hours of the day, and by different resources and global grid is represented in figure 9. As it can be seen, the operation cost of system and thus the value of social welfare function and power quality of system have been improved. The voltage profile at peak hours has been showed in figure 10. As it can be seen the system voltage is in allowed range in this case.

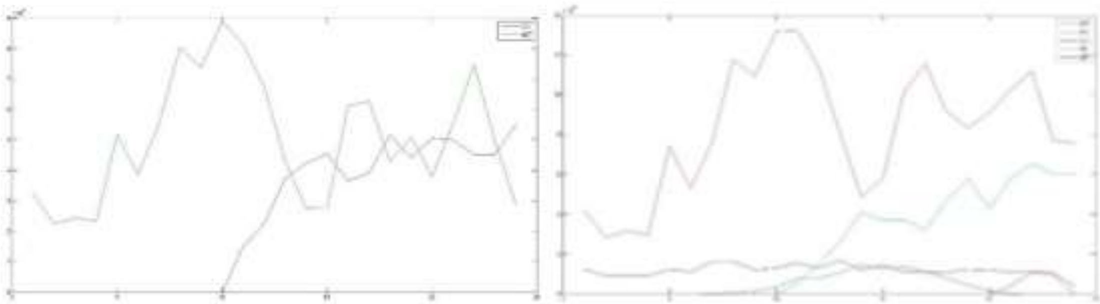

Figure 9. how to operate system resources at different hours of the day and by different resources in the fourth scenario.

Received 03/04/2018
Approved 10/06/2018

Revista Publicando, 5 No 15. (2). 2018, 435-467. ISSN 1390-9304

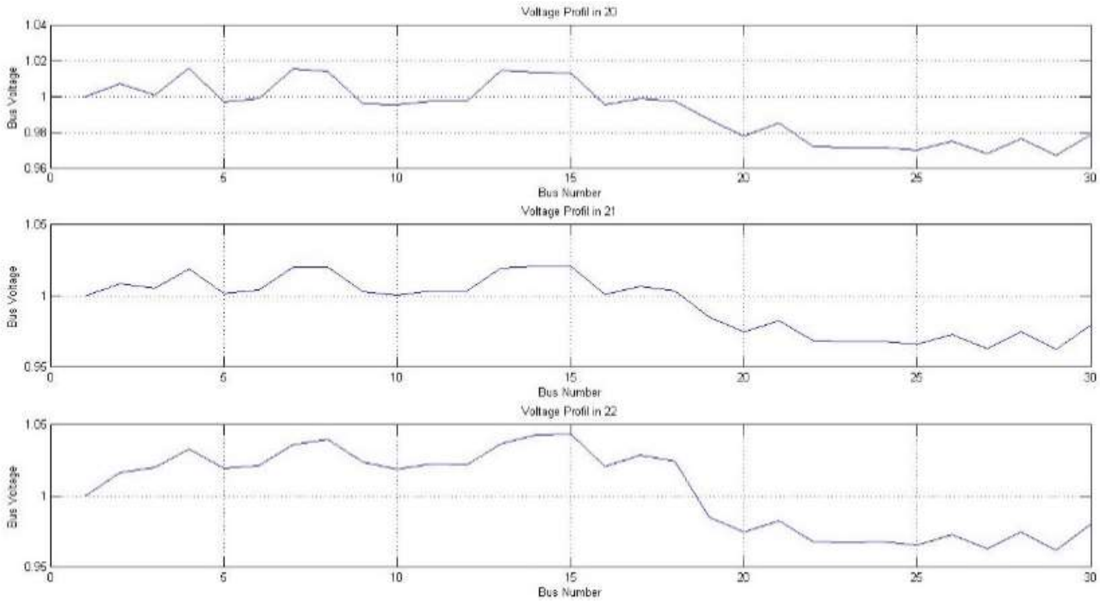

Figure 10. voltage profile at peak hours (20, 21, and 22 O'clock respectively) in the fourth scenario.

The results of system for different optimization scenarios are compared in figure 11.

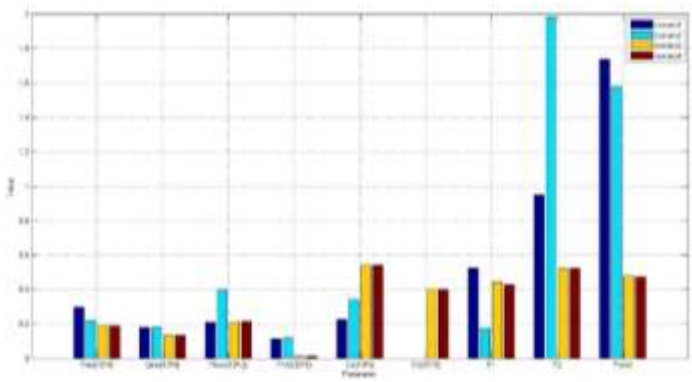

Figure 11. comparing the results of objective function's different parts for different scenarios.

In this step, we compare the results obtained from this algorithm (for scenario 4) with results of other algorithms including PSO, GA and GSO algorithms to study the performance of proposed model and algorithm. In this case, it can be seen that the best result is related to GA-PSO algorithm. The related results ae listed in table 9.

Received 03/04/2018
Approved 10/06/2018

Table 9. The results related to the fourth scenario.

	GA	PSO	GSO	GAPSO
Power losses (kw)	0.00184522	0.00179793	0.001735693	0.00212738
The value of system voltage profile function	10.6127	10.18305	9.791055	11.32028
Consumer surplus impurity ($)	485.4219	465.6671	500.1991	541.4378
System operation cost ($)	404.1621	379.0942	414.6404	401.5753
The normalized value of welfare function	0.73837	0.693057	0.70127	0.42899
The normalized value of power quality	0.3526	0.333357	0.321477	0.52255
Objective function value	0.545488	0.5132075	0.5113751	0.47577

5. CONCLUSION

In this research, the planning of multiple microgrids was done in a competitive market of active and reactive power in which the microgrids use their own internal programmable resources of active and reactive power and renewable resources in parallel to supply their required power. In process presented in this research, microgrids can supply their required power in coordination with other microgrids and global grid and according to offered prices by each of the internal resources, microgrids and global grid. In this article, the problem was implemented on a system with three microgrids that contain different usages including domestic, residential and commercial loads. Finally, it was observed that the best possible response is obtained when the system operates by internal resources and global grid in parallel and in presence of load response. Furthermore, GAPSO algorithm provided the best possible results due to its large search space and high convergence speed compared to other algorithms.

Received 03/04/2018
Approved 10/06/2018

REFERENCES

Thongchart K, Qudaih Y, Yasunori M, Optimum battery energy storage system using PSO considering dynamic demand response for microgrids, 2016, Electrical Power and Energy Systems, Pages: 58 – 66.

Eltamaly A, Mohamed A. M, Abdulrahman I. A, A novel smart grid theory for optimal sizing of hybrid renewable energy systems, 2016, Solar Energy 124, Pages: 26 - 38

Matteo Sola, Giorgio Matteo Vitetta, “A Bayesian Demand-Side Management Strategy for Smart Micro-Grid”, Technology and Economics of Smart Grids and Sustainable Energy, December 2016, 1:8.

Polinpapilinho F. Katina1, Charles B. Keating, Enrico Zio, Adrian V. Gheorghe, “A Criticality-based Approach for the Analysis of Smart Grids” Technol Econ Smart Grids Sustain Energy (2016) 1: 14, DOI 10.1007/s40866-016-0013-2.

Sreenu Sreekumar1 · Jatin Verma1 · Sujil A1 · Rajesh Kumar, “Comparative Analysis of Intelligently Tuned Support Vector Regression Models for Short Term Load Forecasting in Smart Grid Framework”, Technol Econ Smart Grids Sustain Energy (2017) 2: 1, DOI 10.1007/s40866-016-0018-x.

Long-Yi Chang, Yi-Nung Chung, Shi-Jaw Chen, Chao-Lin Kuo, “Demand Response and Ancillary Service Management Using Fractional-Order Integral Indicator and Dynamic Game Model for an Aggregator Program in Smart Grids”, Technol Econ Smart Grids Sustain Energy (2016) 1: 16, DOI 10.1007/s40866-016-0015-0.

Rajeev Kumar Chauhan, C. Phurailatpam, B. S. Rajpurohit, F. M. Gonzalez-Longatt, S. N. Singh, “Demand-Side Management System for Autonomous DC Microgrid for Building” Technol Econ Smart Grids Sustain Energy (2017) 2: 4, DOI 10.1007/s40866-017-0020-y.

Sharmistha Sharma ; SubhadeepBhattacharjee ; Aniruddha Bhattacharya, " Grey wolf optimisation for optimal sizing of battery energy storage device to minimise operation cost of microgrid", IET Generation, Transmission & Distribution (Volume:10 , Issue: 3), 03 March 2016, PP. 625 – 637.

Received 03/04/2018
Approved 10/06/2018

A. Rabiee,A.Soroudi, B. Mohammadi-Ivatlooand M. Parniani, “Corrective voltage control scheme considering demand response and stochastic wind power,” IEEE Trans. Power Syst., vol. 29, no. 6, pp. 2965–2973, Oct2014.

A. Rabiee and A. Soroudi, “Stochastic multiperiod OPF model of power systems with HVDC-connected intermittent wind power generation,” IEEE Trans. Power Del., vol. 29, no. 1, pp. 336–344, Feb.2014.

Mauricio Cepeda, Marcelo Saguan, Assessing long-term effects of demand response policies in wholesale electricity markets, International Journal of Electrical Power & Energy Systems, Volume 74, January 2016, Pages 142–152.

Simona Bigerna, Carlo Andrea Bollino, Demand market power and renewables in the Italian electricity market, Renewable and Sustainable Energy Reviews, Volume 55, March 2016, Pages 1154–1162.

Vincent Rious, Yannick Perez, Fabien Roques, which electricity market design to encourage the development of demand response, Economic Analysis and Policy, Volume 48, December 2015, Pages 128–138.

F.H. Magnago, J. Alemany, J. Lin, Impact of demand response resources on unit commitment and dispatch in a day-ahead electricity market, International Journal of Electrical Power & Energy Systems, Volume 68, June 2015, Pages 142–149.

Manuel Alcázar-Ortega, Carmen Calpe, Thomas Theisen, José Francisco Carbonell-Carretero, Methodology for the identification, evaluation and prioritization of market handicaps which prevent the implementation of Demand Response: Application to European electricity markets, Energy Policy, Volume 86, November 2015, Pages 529–543.

Mohammad Ali FotouhiGhazvini, Pedro Faria, Sergio Ramos, Hugo Morais, Zita Vale, Incentive-based demand response programs designed by asset-light retail electricity providers for the day-ahead market, Energy, Volume 82, 15 March 2015, Pages 786–799.

Mehdi Rahmani-andebili, Modeling nonlinear incentive-based and price-based demand response programs and implementing on real power markets, Electric Power Systems Research, Volume 132, March 2016, Pages 115–124.

Received 03/04/2018
Approved 10/06/2018

Dongsik Jang, JiyongEom, Min Jae Park, Jae Jeung Rho, Variability of electricity load patterns and its effect on demand response: A critical peak pricing experiment on Korean commercial and industrial customers, Energy Policy, Volume 88, January 2016, Pages 11–26.

Qi Wang, Chunyu Zhang, Yi Ding, George Xydis, Jianhui Wang, Jacob Østergaard, Review of real-time electricity markets for integrating Distributed Energy Resources and Demand Response, Applied Energy, Volume 138, 15 January 2015, Pages 695–706.

Mahdi Behrangrad, A review of demand side management business models in the electricity market, Renewable and Sustainable Energy Reviews, Volume 47, July 2015, Pages 270–283.

J. Yan, K. Folly, Investigation of the impact of demand elasticity on electricity market using extended Cournot approach, International Journal of Electrical Power & Energy Systems, Volume 60, September 2014, Pages 347–356.

Nekouei, E., Alpcan, T. Chattopadhyay, D., Game-Theoretic Frameworks for Demand Response in Electricity Markets, Smart Grid, IEEE Transactions on (Volume:6, Issue: 2), 2015, pp. 748 – 758.

Qingqing Huang, Roozbehani, M. Dahleh, M.A., Efficiency-Risk Tradeoffs in Electricity Markets with Dynamic Demand Response, Smart Grid, IEEE Transactions on (Volume:6, Issue:1), 2014, pp. 279 – 290.

Nojavan, S., Mohammadi-Ivatloo, B.; Zare, K., Optimal bidding strategy of electricity retailers using robust optimisation approach considering time-of-use rate demand response programs under market price uncertainties, Generation, Transmission & Distribution, IET (Volume:9, Issue: 4), 2015, pp. 328 – 338.

S. A. Arefifar, Y. A.-R. I. Mohamed, and T. H. M. El-Fouly, “Supplyadequacy- based optimal construction of microgrids in smart distribution systems,” IEEE Trans. Smart Grid, vol. 3, no. 3, pp. 1491–1502, Sep. 2012.

Received 03/04/2018
Approved 10/06/2018