EVALUATING THE ECONOMIZATION OF SMART INDUSTRIAL MICROGRIDS IN IRANIAN POWER DISTRIBUTION COMPANIES USING THE CONCEPTUAL MODEL OF DEVELOPMENT-ORIENTED PLANNING (CASE STUDY: POWER DISTRIBUTION COMPANY OF MAZANDARAN)

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ABSTRACT

The present paper proposes a development-oriented (short-term, medium-term, and long-term) planning model for the existing electricity distribution network in order to develop smart industrial microgrids based on the potential technical and economic capacities in the industrial parks in Iran. The paper first presents a v-shaped planning graph and focuses on the design of the development-oriented conceptual model for smart industrial microgrids according to an economic model. the next step, the objective function regarding the key performance indicators (KPIs) of the proposed model is computed and simulated using ArcGIS 10.2.2 and MATLAB for operating a smart industrial microgrid (including two CHP generators with a total capacity of 2.50 MW) in an active manner within an actual sample area (Sari Industrial Park) subject to Power Distribution Company of Mazandaran.

INTRODUCTION

The privatization of the electricity industry in Iran, the development of local energy communities (LECs), and the decentralized electricity production have made it necessary for power distribution companies to develop smart industrial microgrids with small-scale combined heat and power (CHP) generators to reduce environmental pollutants. The needs for the formation of smart industrial microgrids, which are based on the CHP, the installation and operation of small-scale generators in industrial parks, have encountered the privilege of the private sections due to higher productivity and more indicators that are economical. Therefore, there must be some policies to supply electricity at the place of consumption. Thus, it is necessary to decentralize power plants, improve network reliability, and increase productivity in the framework of the production development for the electrical power companies in Iran. In recent years, the developments and constructions of the industrial parks have grown significantly based on the 20-year vision of the industrial development in country. It has been done to increase the industry's share of Gross Domestic Product (GDP) and to improve the business conditions of the small industries. During the statistical survey, 779 approved industrial parks out of the 952 ones have been exploited up to the end of September in 2017. The breadth of the most industrial parks is about 50 onto 200 hectares, and light and semi-heavy industries are constructed, or they are under the construction [1]. Being depended on the size and volume of the constructed industries or the ones which are under construction, the electricity demand of the industrial parks depending on the size and volume is about 10 to 35 megawatts, and in some cases , it can be to hundred megawatts. These amounts can be more than 10% of the energy consumed in the country [2]. Therefore, the industrial parks face a significant amount of demands of the electrical energy, and in many cases they are also accompanied by thermal energy and cooling demands. The lack of production in the power plants can be eliminated by the construction of CHP generators and the centralized management of its economic and operation activities in each industrial park.It should be done in the form of a microgrid that supports both the national power distribution network and LECs. To design the smart industrial microgrids, an electrical contracting company will provide electricity to the consumers of the industrial parks, which from the delivery point of the entrances of the industrial parks: they receive the electrical energy from the nationwide power grid (Sub Transmission or power distribution network based on the input line voltage level). Due to its need, it modifies or develops the grid constructions; it builds the electricity grids in new industrial parks. Using one or more CHP units, it generates the electricity of consumers' needs inside the industrial parks. Moreover, it undertakes selling energy and electricity services inside the microgrids. In addition, the issue of planning of the smart industrial microgrids can be analyzed by two views: The first one is the technical terms such as the network connectivity, the decentralized energy resources, and voltage control. The second one is the economical one such as general process of development and installation, analytical techniques, economic feasibility, optimal operation of smart industrial microgrids, and so on.

THE ESTIMATION OF DEVELOPMENT-BASED PLANNING MODEL OF THE SMART INDUSTRIAL MICROGRID IN IRANIAN POWER DISTRIBUTION COMPANIES

The need for development-based design and conceptual modeling is required in order to implement and optimize the operation of smart industrial microgrid in Iran. Because of the shortcomings in the economy, the plans of the power distribution companies are based on the kind of resources, which should be allocated to the unlimited needs. Considering the concept of scarcity of resources and various constraints, we must take advantages of the available opportunities and predictable resources in the future. Therefore, we should develop the strategic plans in such a way that they can always be revised. The purpose of the conceptual model in plan is to compile the program parts in a set of independent scenarios at a specified time interval (Short-term, medium-term, long-term). Each scenario is a part of the macro plan. Although it runs undependably, its design at the macro level is like a way that the implementation of each scenario or functional index can impact on timing, the implementation of a set of scenarios or key performance indicators (KPIs) estimated up to the future. Sometimes, these KPIs are either independent or related to each other. Some of these plans may be implemented either at this time (month, year, etc.) or in the future. The categories of plans that all KPIs are designed at this time called short-term ones (Operational). The categories of plans that all KPIs are designed in consecutive periods called medium-term programs (core development). In addition, the ones, which are designed in alternate periods, are called strategic or macro (long-term) programs. (Figure1), the curve V-shape shows the development-based planning model of the smart industrial microgrid. These smart industrial microgrids having CHP are based on the initial formation of the conceptual model and the determination of KPI .By referring to the V-shaped drawing curve, the development-based planning model of the smart industrial microgrids having CHP can be reviewed and designed at three themes including:

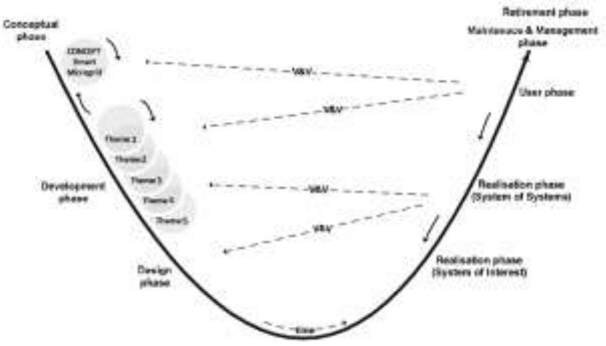

Figure1. Graph V form of the conceptual planning design of smart industrial microgrid based on CHP [3]

Theme01: first theme is to minimize the cost of providing energy for the smart industrial microgrids. There are some items to keep in mind at this level. They include the following items: the development and implementation of short-term plans to estimate the cost components of investment and the functional index , the determination of the optimal amount of CHP (diesel generator), and the installation of electrical energy storage system.

Theme02**:** second theme is to develop and implementation mid-term plans. There are some items to keep in mind at this theme. They include the following items: The estimation of investment income components, the determination of the functional indicator for economic capacity, the installation of CHP resources in industrial smart micro-grid by using GIS location-based information.

Theme03: Third theme is to elaborate and implement a long-term plan by estimating the combination of cost and income components of investment .There are some items to keep in mind at this theme. They include the following items: the functional index, the way of using components installed in smart industrial microgrid, the amount of energy sales / purchases to the national electrical power distribution network in order to minimize the overall cost of supplying the electric grid to the industrial smart-micro grid, etc are presented as a target function.

At this time, we can design and present the proposed top chart of the conceptual model of development plan of smart industrial microgrid with CHP in order to assess the economic process as shown in figure 2.

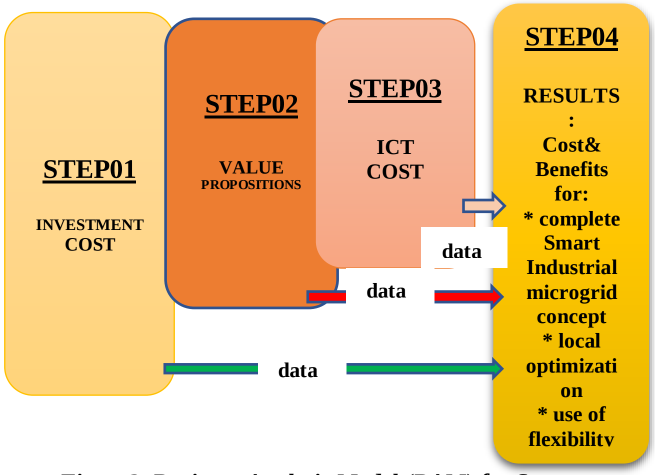

Figure2. Business Analysis Model (BAM) for Smart Industrial Microgrids

To perform a business analysis for smart industrial microgrids, a novel Business Analysis Model (BAM) is developed. As depicted in Figure 2, the BAM consists of four steps. Step 1 is an inventory of the investment cost (consists: initial costs of installing and establish CHP power plants, operating costs: personnel, maintenance, and equipment degradation, costs of fuel purchase, unplanned and planned outages in the distribution network, or production uncertainties, etc.) within industrial parks. Step 2 defines value propositions (consists: sale of electricity produced by CHP generators to the national power distribution network with a five-year guaranteed purchase contract, sale of electricity to private and commercial consumers in industrial parks, use of governmental incentive policies in this regard and so on.) within the concept of smart industrial micrograds. Step 3 summarizes ICT related costs (consists: costs of GIS-based monitoring and control for energy loss in CHP power plants, microgrid, and upstream distribution network with the aim of improving the power distribution among the consumers in industrial Parks.) associated with smart industrial microgrids. Finally, step 4 calculates several results based on input variables as stated in step 1, 2 and

3. Some of these variables are however unpredictable or may vary, because of changing contextual surroundings.

DETERMINING PERFORMANCE INDICATORS (KPIs) OF THE CONCEPTUAL MODEL OF THE DEVELOPMENT-ORIENTED PLAN OF SMART INDUSTRIAL MICROGRIDS

The object function of KPI, which is the proposed model for this paper, includes reducing equipment investment costs and operating costs except the revenue from the sale of electrical energy to the local grid of industrial parks. Moreover, it is in the midst of a development-oriented planning model, and it is simulated and calculated by the equation (1):

$$KPI_{OF} = \min\left\{\begin{array}{l} IC_{ann}^{CHP} + IC_{ann}^{Boiler} + OC^{CHP} + \\ OC^{Loss} + MC^{CHP} + MC^{Boiler} \\ + OC^{EM} + OC^{LS} + OC^{Buy} - IC^{Sell} \end{array}\right\} \quad (1)$$

IC represents the investment cost, OC represents the operating cost, MC represents the maintenance cost, OC^{LOSS} represents the opening-cost of network losses, which is due to the flow of electric current per unit of production. OC^{EM} represents the opening-cost of pollution for each grid production unit, OC^{LS} represents the unsecured electricity cost. OC^{Buy} represents the purchase cost of the electrical energy from the network, IC^{Sell} represents the purchase cost of electrical energy to the network. The CHP and boiler indices are also related to the boiler production system .

A) Short-term Planning: The first part is in the conceptual model of KPI, the determination of the required equipment and the amount of annual savings is due to the use of CHP generators. Therefore, operating costs (OC) of CHP generators of smart industrial microgrids include purchasing costs, initial installations (IC_{IN}), fuel costs (C_{GA}), costs of emissions per the production units (OC^{EM}), first year maintenance costs (MC) which are calculated by equation (2):

$$OC_{ann}^{CHP} = IC_{IN} + MC' + C_{GA} \quad (2)$$

The fuel costs are also a function of CHP technology efficiency and fuel costs. The dependence of operating costs on fuel prices will result in the dependence of the total cost savings on fuel prices. The fuel cost in terms of the output power of CHP can be simulated as a quadratic equation.

The process of repairs and maintenance of smart industrial microgrids has CHP in the KPI target function. This means that the planned activities for the maintenance of the power distribution network equipment are in line with the timing. The capital constraints in power distribution companies can make less effort to rebuild or strengthen the facility and network. Therefore, the cost of repairs, maintenance, the off-schedules, and offsets of smart industrial microgrids with CHP are important.

B) Medium-term Planning: Medium-term planning is to estimate the costs of smart industrial microgrids energy by considering the type of energy exchange and the status of the CHP utility of generators (can be connected or independent of electricity distribution network), the costs of purchases and electricity sales from / to the network that are computed from relations (3) to (4):

$$IC^{sell} = \sum_{y,m,d,h} \left(P_{y,m,d,h}^{sell} * Price_{y,m,d,h}^{sell} \right) * ATP \quad (3)$$

$$OC^{Buy} = \sum_{y} \sum_{m} \left(\sum_{i} \begin{array}{l} \left(E_{y,m,i}^{Buy} * Price_{i}^{Buy} \right) + \\ E_{y,m}^{Buy-P} * Price^{P} \\ - E_{y,m}^{Buy-L} * Price^{L} \end{array} \right) * ATP \quad (4)$$

P^{Sell} is the amount of energy from the sale of energy to the network a kilowatt per an hour, $Price^{Sell}$ is earning the energy sales to the network for one kilowatt per an hour, ،E^{Buy} ، E^{Buy-P} ، E^{Buy-L} respectively represent the amount of purchased energy at the time of the medium charging, peak charging, and low charging. They are obtained from the sum of energy purchased during these hours.

In recent years, policy makers have been trying to reduce air pollution by producing CHP (including CO2, SO2 and NOX). The amount of pollutants produced in Iran is about 860 g/ kWh by gas-consumption power plants. According to the Kyoto agreement, for each ton of pollution reduction $8 is considered. In accordance with the rule 13, the proposed KPI target function can be analyzed and calculated by equation (5):

$$OC_{i,t}^{EM} = C_{co2,i,t} + C_{NOx,i,t} + C_{SO2,i,t} \pm EM \quad (5)$$

OC^{EM} represents the cost of pollutants including (CO2, NOX, SO_2) for each CHP producing unit per time (t), EM represents the amount of cost difference of generating emissions than CHP non-production state of smart industrial microgrids [4].

(C) The Long-term Planning: The calculation of distribution network losses along with smart industrial microgrids manufacturing is one of the most complex issues, and there are various solutions for it. However, the use of network of GIS-based load is more accurate than all proposed methods. In order to measure network losses throughout the year, the electric load calculations are performed hour to hour. The total losses of the network are calculated in the one-year period. It should be noted that the electric load, the energy price and output power of CHP units are considered as variables. Therefore, optimizations can be used instead of power losses at the cost of annual energy losses. The network load is estimated in several steps per year by electric charging factors in kilowatt. These coefficients actually represent the ratio of the electric loads of each step to the network's peak. As all electricity required by the smart industrial microgrids is supplied from the power distribution network, the cost of losses is also calculated based on the electricity cost. According to this goal, the cost reduction is when all electricity provided from the power distribution network of the industrial parks. Therefore, this is a cost considered for the loss in the optimization question, and this is calculated with regard to the electricity purchase price from the network. In addition, the cost loss function is calculated from the equation (6):

$$OC^{Loss} = \sum_{t}^{T} (Price^{Buy}(k) \times E_{loss}(k)) + LP + VP \quad (6)$$

$Price^{Buy}$ represents the purchase price of electricity from the nationwide network in k, E_{loss} represents the lost energy in the micro grid in step k, and LP‹VP represents penalty coefficients if there is a voltage drop, the problem of charging percentage lines is added to the cost of energy losses [5].

The CHP location and capacity can be determined in smart industrial microgrids by using the GIS information. It leads to lower investment costs, cost of losses, maintenance and exploitation.

Determining the location and optimal capacity of CHP generators is done in GIS software. Due to the range of power, the estimated geographic distribution of the supply power distribution network, industrial park and productive capacity in terms of its type are dedicated to and done in GIS software. The power can be stepped up, and then the Optimal Power Flow (OPF) results are observed. After that, this is done for the different buses of the smart industrial microgrids. Finally, the best point to construct a generator is proposed in GIS as stated by the results of load distribution in different buses and powers.

RESULTS

This paper is intended to implement a smart industrial microgrid by using GIS descriptive and spatial information in a real industrial park. (Sari city with total industrial park: 55 hectares, and the operational phase industrial park: 53.4 hectares and industrial phase: 44 hectares) The smart industrial microgrid can be run and simulated by considering the structure of figure 3 along with CHP generator and two sets of diesel generator (The diesel generator as a CHP generator).

Figure3. shows the process of construction and operation of CHP generators in the industrial park of Sari

Table 2 and Figure 4 can simulate the basic information required for the conceptual design model and functional indicators of the smart industrial microgrid.

Equipping CHP	Specifications Type	CHP01	CHP02
Diesel	Engine Power (KW)	440	360
	rpm	1500	
	Number of cylinders	6	
	fuel type	Gasoline	
	Tank capacity (liters)	1490	
	Fuel consumption (liters / hour)	150.8	
	Useful life (hours)	8000	
Generator	rpm	1500	
	Generator Power (KVA)	500	360
	Power factor	0.8	
	Phase number	3	
	Voltage (V)	400	
	Flow (amp)	772	480
	Frequency (Hz)	50	
	cooling system	water	
	Price: (million IRR)	5500	3550

Table2. shows the basic information of the CHP generators of the smart industrial microgrid sample

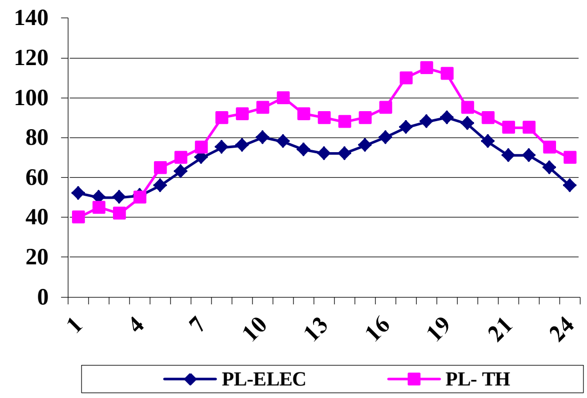

Figure4. the graph of the demand for electricity and heat in (24 hours) in kilowatt of CHP generators

The next step, we are to evaluate the cost estimation and simulation of the conceptual model of the smart industrial microgrid prototype by the maximum performance of CHP generators with a performance index of 0.917. Moreover, coding was done by MATLAB software in a five-year supportive period. It should be noted that basic purchase price of electricity by government is assumed 900 IRR (Iranian Rial) per kilowatt hour. Since diesel is used for emergency situations, the initial purchase price of a new diesel generator is also included in the calculation. (Investment cost). Table3 shows the results of the simulation of the functional indicators of the proposed conceptual model including the incomes and costs of generating CHP smart industrial microgrid in this survey.

The Performance Index (Million $ / kWh)	The Levels examined index (KIP)				
	CHP01	CHP02	M.G*	Grid**	Total cost (million $)
IC	8.45		10.90	7.20	26.55
OC	6.08		9.35	11.00	26.43
MC	1.25		2.54	3.18	6.97
OC^{EM}	0.108		0.120	0.101	0.329
OC^{LS}	5.55			9.01	14.56
OC^{LOSS}	4.69			6.50	11.19
IC^{Sell}	10.229				

Project life: 10 years, interest rate and inflation: 15%.
*The costs of constructing and developing smart grid industry are exemplary
** The costs of developing and upgrading the upstream distribution network

Table 3.The estimation of performance indicators of the conceptual model of development plan

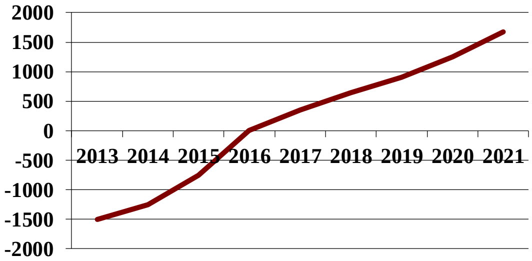

Figure5. shows returning on investment chart for the smart industrial microgrid

Specifying the cost coefficients , we can determine the electricity, heat, power generation costs and CHP electricity and heat costs. In other words, the CHP cost function is the one of the combined power generator functions and heat producers. The above functions, the amount of the received electricity or the transmitted one to the network is determined by transmitting power at the cost of electricity. The cash flow and the smart industrial microgrid investment return with CHP in the survey is studied by considering the annual adjustment rate of electricity purchase price by 20%. Its curve is shown in figure5. According to the conceptual model of planning and performance indicators presented in the article, it is necessary to estimate the losses of the smart industrial microgrid to optimize the location of CHP generators by using the OPF based on GIS information. Figure 6 shows the result of the simulation of the Arc GIS10.2.2 software.

Figure6. The smart industrial microgrid loss situation with CHP based on OPF and GIS data

CONCLUSION

This paper believes that the promotion of the economic growth and the development of the core of smart industrial microgrids require different factors including the optimal productivity of both financial resources and the available technical facilities, the favorable use of quantitative electricity generation (CHP) and the operational plan. This issue has a special priority in power distribution companies. By reviewing the results of the article, we can find that the use of the CHP system makes significant savings in total costs and energy consumption. The increase in the number and capacity of CHP generators also improves the process of reducing grid losses and upstream power distribution networks. If there is an option to sell the electricity to the network , the use of the CHP system will benefit the electricity distributing company. It should be noted that as the country's economic grows, the smart industrial microgrids energy consumption rises, and there is a two-way relationship between energy consumption and economic growth. Thus, the implementation of intelligent industrial smart-micro grid based on CHP generators and GIS information in the power distribution network should be done through step-by-step studies and plans. The amount of initial investment appropriate to the volume of facilities created for the establishment of such a network should be calculated , and the amount of losses and the saved energy should be specified leading to the development of the application. Moreover, the design and development of a conceptual model of the economic planning of smart industrial microgrids having CHP becomes possible in industrial parks. The optimization of electricity services in these parks also gets possible through the intelligent communication tools and the methods based on location-based GIS information of power distribution networks. Today's GIS database is one of the major infrastructures of creating smart industrial microgrids in the power distribution companies. It can provide a two-way communication for consumers and the automatic control of load consumption in urgent situations. Industrial consumers (Diamond) can pay it less through smart management and GIS-driven on *energy consumption in peak hours. Besides, the* environmental experts can also take advantage of this design based on modern technologies to resolve climate change and avoid excessive carbon emissions.

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