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Optimal planning in a developing industrial microgrid with sensitive loads

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HIGHLIGHTS

- Optimal microgrid planning for industrial estate as a new work.
- Enhancing power quality, reliability and security of CNC workshops (sensitive loads).
- Load forecasting in details considering the end users devices and load factors.
- Sensitivity analysis on uncertain parameters in details.

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ABSTRACT

Computer numerical control (CNC) machines are known as sensitive loads in industrial estates. These machines require reliable and qualified electricity in their often long work periods. Supplying these loads with distributed energy resources (DERs) in a microgrid (MG) can be done as an appropriate solution. The aim of this paper is to analyze the implementation potential of a real and developing MG in Shad-Abad industrial estate, Tehran, Iran. Three MG planning objectives are considered including assurance of sustainable and secure operation of CNC machines as sensitive loads, minimizing the costs of MG construction and operation, and using available capacities to penetrate the highest possible renewable energy sources (RESs) which subsequently results in decreasing the air pollutants specially carbon dioxide (CO_2). The HOMER (hybrid optimization model for electric renewable) software is used to specify the technical feasibility of MG planning and to select the best plan economically and environmentally. Different scenarios are considered in this regard to determine suitable capacity of production participants, and to assess the MG indices such as the reliability.

1. Introduction

Nowadays, one of the most important environmental issues is global warming and constantly-increased air pollution by fossil fuels (Leung et al., 2014). Over the past century, atmospheric CO_2 level has increased more than 39% in May 2013 with a corresponding increase in global surface temperature of about 0.8 °C (NOAA, 2016). RESs can be an appropriate solution for this problem according to the researchers and policy makers' outcomes (Ngan and Tan, 2012). Wind turbines (WTs), photovoltaic (PV) panels, geothermal power plants and other technologies are the best way to generate electrical energy without any air pollutions (Prodromidis and Coutelieris, 2010).

On the other hand, sensitive loads are increased due to industrialization, social welfare improvement and energy technologies development. The CNC machines have been known as very common and also sensitive loads in the lathing and milling industries in which computers play an integral role. These machines do lathe and mill operations with the precision of micrometer during uninterrupted hours. Variable frequency drives (VFDs) are applied to the CNC equipment to regulate the servo motors, control the axes motion, etc. All of these processes are required to highly-detailed components are created from raw materials. Due to the presence of VFDs as sensitive and expensive interfaces, continuous CNC work condition, and the importance of the produced components, CNC machines are considered as sensitive loads from the power supply point of view. Any issue corresponding to power quality concepts such as voltage sag, fluctuation, overvoltage and interruption can cause irreparable events such as accident of CNC machine's axes, the sensitive component failing or destroying, and the VFD burning. Each one of these events will be followed with financial damages, imposed on CNC workshop owners, while electrical distribution companies are responsible for supplying the

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Table 1
A typical CNC machine consumption in a normal working hour.

Electrical load type	Nominal capacity (kW)	Load factor (%)
X-axis servo motor	2	50
Y-axis servo motor	2	50
Z-axis servo motor	2	50
Spindle servo motor	11	100
Hydraulic pump motor	3	100
Lubrication pump motor	0.2	16
Cooling fan motor	0.5	100
Chip conveyor motor	1	20
Flood coolant motor	1	30
Total losses (drives, contactors etc.)	1	100

electricity with appropriate power quality. Refs. (Morinec, 2000, 2002; Vasconcellos et al., 2010) represent some ways to improve power quality in the presence of CNC machines as sensitive loads such as grounding. Nevertheless, providing an independent, secure and reliable supply may be better solution and should be studied.

DERs including conventional distributed generations, RESs, and energy storage sources are introduced as appropriate resources to meet the loads locally. These resources are integrated with local loads as MGs (Sorensen, 2011; Twidell and Weir, 2015; Botelho et al., 2016) which can operate in both grid-connected and islanded modes (Babazadeh and Karimi, 2013). As a solution, MGs undertake to facilitate the wide penetration and integration of RESs and energy storage devices into the power system in developing countries, increase feasibility of off-grid electrification, reduce system losses and greenhouse gas emissions, and increase the reliability (Louie, 2016; Manas, 2015; Li et al., 2016; Peerapong and Limmeechokchai, 2017; Kobayakawa and Kandpal, 2016). Due to their potential benefits of providing source, efficient, reliable, sustainable, and environmentally-friendly electricity from RESs, MGs are taken into account more than ever (Bevrani et al., 2017). MGs construction is growing in different areas like military regions, universities, industrial estates and etc. due to the mentioned reasons. The industrial estates are interested in because of their enormous greenhouse gasses emission and existence of sensitive loads such as induction furnaces and CNC machines. In fact, the importance of the sensitive loads is another reason to plan and construct an MG in the industrial estates.

One of the important issues in MG planning is determining the optimal size of its resources to meet the load so that the objective function is minimized/maximized and technical constraints are met. Economic, environmental, and reliability-based indices are used as objective functions in the planning formulation of the MGs. Different software and optimization techniques are used to optimal sizing of MGs in the literature. HOMER is the powerful software which is used by many researchers for optimal planning of MGs (Bahramara et al., 2016; Olatomiwa, 2016).

The main contributions of the presented work are summarized as follows:

- Optimal MG planning in the industrial estate is done which does not take account enough in the literature. The main idea is enhancing power quality, reliability and security of CNC workshops as sensitive loads by implementation of an MG.
- Load forecasting is done in details considering the end users devices and their load factors, while in the most previous studies, monthly average load consumption is only considered for simulation.
- Sensitivity analysis on uncertain parameters is done in details which this subject is not investigated well in the literature yet.

The rest of this paper is organized as follows. Section 2 presents the description of HOMER input parameters. In Section 3, system description and specification is presented. The economic analysis is prepared in Section 4. In Section 5, simulations are conducted and discussed. Finally, conclusion is done in Section 6.

Table 2
Consumption of a typical manual lathing/milling machine in a normal working hour.

Electrical load type	Nominal capacity (kW)	Load factor (%)
Common X and Z axes motor	5	100
Spindle motor	1	100
Flood coolant motor	0.5	30

2. Description of input parameters

The HOMER software needs some input parameters for simulation including load profile, solar radiation, wind resource, RESs capacity, initial costs per unit for each component, etc. These parameters is further enlarged in the following subsections.

2.1. Load profile of the CNC workshops set

In this study, a set of eight CNC workshops is selected as the total load to test the feasibility of the designed MG. This set is located in 11 Fath, Shad-Abad industrial estate, Tehran, Iran. Every workshop has certain and individual CNC machines and other equipment. However, all of them are similar in viewpoint of consumed energy type. Nevertheless, their energy consumptions are different. An average load is considered for all workshops instead of their different consumptions to facilitate the load estimation. In this study, based on the nearby workshops visit, the certain equipment and consumptions are considered for all workshops containing CNC machines, manual lathing/milling machines, lighting, and miscellaneous consumptions such as air-conditioning, computers, refrigerators, etc. On average, every workshop has three CNC machines, two manual lathe/milling machines, ten 46 W duplex lamps and 2 kW equivalent consumption of miscellaneous equipment. Since the majority of CNC machines whether milling or lathing are three-axis or can expand to it, they are considered three-axis on average in this paper. A typical consumption of a three-axis CNC is described in Table 1. In addition to the nominal capacity of a motor, its load factor is considered to show the real average time of motor involvement. Similarly, Table 2 shows the consumption of a typical manual lathing/milling machine. According to this detailed consumptions, the total consumption of a CNC workshop is calculated in Table 3. Finally, the maximum consumption of the eight workshops that is the peak load of the MG, is obtained 577.76 kW.

The CNC workshops as the MG loads work about simultaneously from 8 a.m. to 5 p.m. Therefore, consumption timing of CNC workshops with respect to each other is similar. On the other hand, the timing of different consumptions of each CNC workshop itself is similar on average. In addition, basic changes in the CNC workshops activities happen monthly and seasonally. All of these