ROBUST AND RELIABLE DESIGN OF A MICRO-GRID SUPPLY CHAIN BASED ON PHOTOVOLTAIC ENERGY IN PRESENCE OF SYSTEM DISRUPTIONS (CASE STUDY: YAZD; A SUNNY CITY WITH 320 DAYS SUNSHINE)

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ABSTRACT

Nowadays, robust and reliable supplying of the energy plays a key role in the fast economic world. On the other hand, the desire to supply micro-grid energy, especially renewable energy, has increased significantly. In this paper, an efficient approach is proposed in order to design a robust and reliable micro-grid supply chain based on photovoltaic energy. The integrated approach utilizes from the benefits of cause and effect diagram, brain storming method, Delphy method, and FMEA. The obtained practical results of the case study (Yazd University) represent the efficiency of the proposed approach such that the risk indicator of the micro-grid supply chain is reduced 20% based on photovoltaic energy. Moreover, the operational costs are shrunk 15%.

INTRODUCTION

Most of the electricity currently produced in IRAN is generated as a part of a centralized power system. This system has been designed around large fossil fuel power stations. Although this power system is robust and reliable, the efficiency of power generation is not high, resulting in a considerable quantity of waste heat. The subject of this study is addressed to investigate an efficient alternative approach: the robust and reliable energy production by micro-grid energy production system, based on photovoltaic energy, in close proximity to the energy users in the presence of any system disruption factors (e.g., dust, hot dry weather, human mistakes in maintenance etc.).

A micro-grid is a small-scale power supply network that is designed to provide power for a small community. The definition of the "small community" may range from a typical housing estate, isolated rural communities, to mixed suburban environments, academic or public communities such as schools or universities, to commercial areas, trading estates, industrial sites, or municipal regions.

Several studies considered the subject of micro-grid supply chain. Sharkh et al. (2006) investigated a practical concept such that how the energy production by small scale generators in close proximity to the energy users can integrate into micro-grids systems[1]. Silvente et al. (2015) focused on the development of optimization-based scheduling strategies for coordination of micro-grids[2]. Marzband et al. (2017) studied a real-time flexible central energy management system for all types of home Micro-grids. They developed a framework of the retail electricity market in a distribution system to enhance the performance of the home Micro-grid system[3].

Also, some of researchers studied the micro-grid reliability. Kennedy (2009) introduced an evaluation methodology for islanded micro-grids that realistically represents stochastic resources and explicitly examines the influence of supply-to-load correlation on reliability[4]. Borges et al. (2011) presented a model for reliability evaluation of micro-grids with Distributed Generation based on renewable energy resources[5]. Jones (2015) identified and quantified the risks for micro-grids and distributed generation, as might be associated with product design parameters, long-term maintenance strategies, and weather-induced outages occurring on the local utility system[6]. Ferruzzi et al. (2016) proposed a decision method for energy bids in the Day-Ahead energy market[7]. Recently, Talapour et al. (2018) presented a reliable micro-grid for residential community with modified control techniques to achieve enhanced operation during grid connected, islanded and re-synchronization mode[8].

This paper aims to consider the system disruption factors and design a robust/reliable micro-grid supply chain based on photovoltaic energy. The main benefits of designing such micro-grid supply chain are obtaining a resilient electrical energy supply. Moreover, the operational costs of the supply chain can be significantly reduced.

THE PROPOSED APPROACH

In a nutshell, the main steps of the proposed approach for the subject of the paper can be explained as follows: (A) General points: the present technical/economic conditions of the case study are carefully investigated. (B) Extract of that main risk causes: the main causes of the risk/uncertainty of the micro-grid supply chain based on photovoltaic energy are extracted. (C) A cause and effect diagram is established. (D) Causes ranking: some integrated effective methods are applied for ranking of causes. (E) Efficient solutions for risk reduction: the efficient solutions to remove/reduce risks of the micro-grid supply chain are determined by Delphy and brainstorming techniques. (F) Micro-grid supply chain design: by considering the efficient solutions of the previous step, the robust and reliable micro-grid supply chain based on photovoltaic energy is designed/redesigned. (G) Case study: Yazd, a sunny city with 320 days sunshine, is selected. As an especial region, Yazd University is nominated as a case study and the obtained practical results are reported.

At the following, the detailed description of each step can be obtained.

(A) The considered micro-grid is designed for a national university, named Yazd University, which has 14000 bachelors, M.S., and Ph.D. students. This university has 1000 academic staff and employers. The total square of the university area is 1500000 M^3.

As a significant point, Yazd is a sunny city with 320 days sunshine. On the other hand, some technical reasons (e.g., desert thunderstorms, dust and tornadoes, high temperatures), human reasons, financial reasons, the reliability of several technical systems can be varied. This can cause to several system disruption.

Because of several reasons (e.g., the importance of the quality of education, and power supply for the technical experiments and practical tests), robust and reliable power supply plays a key role for managerial group and regional level.

The target is robust and reliable designing of a micro-grid supply chain based on photovoltaic energy for this university in the presence of system disruptions.

(B) Extract of that main risk causes: According to the structure of the micro-grid supply chain which can be established for the Yazd University, the literature review, the specific geographical conditions of the Yazd city, and the brain storming with related experts, the main causes of the risk/uncertainty of the micro-grid supply chain based on photovoltaic energy can be extracted as Table (1).

Table (1): Main causes of the risks of the micro-grid supply chain based on photovoltaic energy

Risk Number	Elements of Process	Title of Process
R1	Lack of power supplies	Supply and purchase of energy
R2	Lack of proper and adequate supply of energy supplies	
R3	International developments and external influences	
R4	Low quality of facilities (exploitation and subscribers) purchased	Operation processes
R5	Exchange rate fluctuations (for foreign purchases of utilities and subscribers)	
R6	Lack of access to the market equipment	
R7	No immediate access to the operator in critical circumstances	
R8	Delay in the provision of utilities	
R9	Inadequate inventory of equipment in stock	
R10	Lack of timely implementation of maintenance programs	
R11	Lack of skill and precision of officers during periodical visits to the maintenance	
R12	Non-calibrating measuring instruments	
R13	Manual recording of information in paper forms and as a result increase human error	
R14	Lack of adequate supervision over the process of production and testing of concrete foundations	
R15	Environmental fluctuations and climatic events such as dust	
R16	Lack of adequate skill of contractor personnel	
R17	Lack of evaluation and proper selection of contractors	
R18	Lack of sense of responsibility and incentive for contractors	
R19	Lack of proper supervision of contractors' performance	
R20	Cloudy days	photovoltaic energy
R21	Black whirlwinds	
R22	Several types of dust	
R23	Lack of proper management and planning in exploitation and netting processes	Managerial Processes
R24	Inappropriate project management and poor use of project control disciplines	

As it can be concluded from the Table (1), 24 causes in four categories can be caused by the significant system disruption in the micro-grid power supply chain of the Yazd University.

(C) The cause and effect diagram: The Table (1) can be represented as a cause and effect diagram. Because of the limited volume of the paper, this diagram is deleted here.

(D) As a remarkable point, the investment budget and working time of the university is limited and the university wants to obtain the maximum improvement in the robustness and reliability of the micro-grid systems by assigning the minimum investment budget and working time. Accordingly, the major causes were selected by FMEA method. For evaluating the causes in Table (1), the key indicator, represented in Table (2), are considered.

Table (2): List of risk evaluation indicators, extracted from literature and brain storming method

No.	Evaluation indicator
1	Impact on blackout
2	Organizational Disability in Response to Risk
3	Impact on Subscribers Satisfaction
4	Impact on community and environmental safety
5	Severity of risk
6	Occurrence probability of risk
7	Discovery rate of risk

After evaluating and ranking of the cause of Table (1), ten main causes are specified as Table (3) with the related RPN number.

Table (3): List of critical risks based on FMEA method

No.	Risk title	Severity (R)	Probability (P)	Detection (N)	RPN	Rank
1	Lack of liquidity of purchasing electricity and paying for operating costs	7	7	4	196	1
2	Lack of access to the market equipment	8	7	3	189	2
3	Lack of proper supervision of contractors' performance	6	6	5	180	3
4	Inadequate inventory of equipment in stock	5	7	5	175	4
5	Lack of power supplies	6	7	4	168	5
6	Low quality of the purchased facilities	6	5	5	150	9
7	Hand-written information on paper forms	7	7	3	147	10

(E) Efficient solutions for risk reduction: the efficient solutions to remove/reduce risks of the micro-grid supply chain are determined by Delphy and brainstorming techniques. six solution approaches are suggested are as follows:

I. Proposing an efficient model for forecasting of equipment supply and budget estimation.
II. Determining of the maintenance schema and

reliability function for technical equipment of micro-grid supply chain.

III. Designing and developing a comprehensive statistical system for needed service parts of the micro-grid supply chain based on photovoltaic energy.

IV. Executing of an efficient economic order quantity (EOQ) and inventory system for operational processes.

V. Applying a weather forecast system accurately for up to 3 months.

VI. Implementation of the Six Sigma System to track costs and incomes and thus reduce current costs.

(F) Micro-grid supply chain design: by considering the efficient solutions of the previous step, the robust and reliable micro-grid supply chain based on photovoltaic energy is designed/redesigned.

(G) Case study: Yazd, a sunny city with 320 days sunshine, is selected. As an especial region, Yazd University is nominated as a case study and the obtained practical results are reported.

THE MAIN RESULTS/OUTCOMES

In order to evaluate the efficiency of the proposed approach, several performance evaluation indicators can be applied. Some of the main indicators are as following: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI), Customers experiencing multiple interruptions, Average system interruption frequency index, Average system interruption duration index, Energy has not supplied index, Average Energy not supplied index.

The mentioned indicators were calculated and the average value of each indicator change were considered. The obtained practical results represent the efficiency of the proposed approach such that the risk indicator of the micro-grid supply chain based on photovoltaic energy is reduced 20%. Moreover, the operational costs have shrunk 15%.

CONCLUSIONS AND FUTHER WORKS

In this paper, an efficient approach is proposed in order to design a robust and reliable micro-grid supply chain based on photovoltaic energy. The integrated approach utilizes from the benefits of cause and effect diagram, brain storming method, Delphy method, and FMEA. The obtained practical results represent the efficiency of the proposed approach such that the risk indicator of the micro-grid supply chain based on photovoltaic energy is reduced 20%. Moreover, the operational costs have shrunk 15%.

Future directions and extra works are recommended as follows. First, the proposed robust and reliable design can be considered and customized for other micro-grid supply chain such as hospitals, regional post offices, and several services offices. Second, the proposed approach can be integrated with some technique of muti-criteria decision making (MCDM) (e.g., Taxonomy method) and compared with the proposed approach.

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