ISOLATED MICROGRID DESIGN PROBLEM CONSIDERING RESILIECY INDICES

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ABSTRACT

In the last decade, the microgrid concept has been widely regarded as important issues in the literature as well as in the practice. Reducing greenhouse gases, reduction of transmission losses, enhancement in the passive defence strategies and increscent in the local reliability are the main interests in the using of microgrid systems. On the other hand, isolated microgrid systems have been broadly implemented in the remote sites where an interconnection with the main grid is not feasible due to either technical or economic constraints. In this paper, we investigate isolated microgrid design problem considering natural disaster. Indeed, the performance of Distributed Generation (DG) systems are evaluated in the disaster events according to the resiliency indices and finally the model is proposed to minimize the microgrid initial investment costs considering resiliency and reliability constraints.

INTRODUCTION

Nowadays, the penetration of DG systems across the power supply networks has been rapidly increased. Generally, DG systems comprised from the several developed technologies including Photovoltaic (PV) panels, Wind Turbines (WT), diesel generators and micro turbine technology that are cooperated with the administration unit to operate in the best condition. The microgrid concept first entered to the literature by Lasseter [1] as combination of renewable energy technologies to generate power and heat at residential industrial plants or commercial buildings. On the other hand, Lopes et al [2] defined microgrids as Low Voltage (LV) network that connected to several small modular generation systems and additionally generate power and heat. Furthermore, Lopes et al. [2] investigated and evaluated the control strategies for microgrids islanded operation. Moreover, storage devices and load shedding strategies is included in this paper. Designing and implementing isolated microgrids have been indicated and emphasized in many research areas [2,3,4]. Therefore, designing of the reliable and resilient isolated microgrid network are mostly interested considering customers satisfaction criteria. In the last several years, the network resiliency in the major disaster faults alongside of environmental, economic and network reliability characteristics introduced in the power network designing literature growingly. Although there is not a comprehensive and agreed definition upon the resiliency concept, but a most acceptable resiliency definition can be considered as the ability of systems to anticipate, absorb, and rapidly recover to the normal state from an external, high-impact and low-probability events [5]. Indeed, exceptional events affect the microgrid production performance and increase the probability of vulnerabilities in the electricity supply. Therefore, determination of resiliency factors in the DG systems and optimizing microgrid structure considering initial financial investments and reliability and resiliency constraints outline the base of designing problem in the future.

In this paper, we studied the resiliency factors in an isolated microgrid network including PV systems, diesel generators, WT, and Energy Storage Systems (ESS). Furthermore, to calculate the resiliency factors, gasoline shortages probabilities, wind and solar radiation unexpected patterns extracted from the previous stored data and the experts´ opinions. The wind speed values and solar radiation data were collected in three years (2014-2016) in 10 minutes intervals and fuel shortage probabilities was investigated according to the critical events in the past 10 years. Resiliency factors were collected with the 50 experts' point of views and the results summarized in 7 items including the residency of system in 1) Earthquake (more than 6 Richter), 2) Flood, 3) Severe storm, 4) Heavy snow, 5) Intense heat, 6) Heavy rain, and 7) Explosion and the evaluation process was implemented based on the DG systems characteristics. On the other hand, DG systems initial investment and annual maintenance costs are important parameters that can affect the microgrid designing problem.

RELIABILITY AND RESILIENCY

Reliability and resiliency are related in some aspects but are not the same. Reliability is defined generally as the ability of the power system to supply electricity in the right quantity and quality in the customers region. Moreover, reliability concept is measured according to the interruption indices. Additionally, the reliability considers the high probability with low impact interruption events. On the other hand, the resiliency concept emphasises on reducing the effect of low probability with high risk disruptive events and tries to recover the systems for sustained period of times after the disaster events [6]. Therefore, the resiliency concept considers power system recovery time as well as the customer interruption time and focuses on measuring of the disaster consequences. Additionally, Table 1 indicates the difference between the reliability and resiliency concept in a brief description.

Table 1. Reliability and resiliency comparison

Reliability	Resiliency
▪ Considers high probability with low disruption events	▪ Considers low probability with high consequence events
▪ Concerned with customer interruption time	▪ Concerned with customer interruption time and the infrastructure recovery time
▪ Focuses on measuring the system state	▪ Focuses on measuring the event consequences
▪ Reliability is the outcome	▪ Resiliency is the way you achieve the outcome

DESIGNING PROBLEM

In this paper, we try to find the best use of the DG systems in the isolated microgrid networks according to the investment costs objectives. Furthermore, the problem considers satisfying the reliability and resiliency restrictions as mandatory constraints in addition to the other designing constraints. The model´s objective function is consisting of DG system initial costs, maintenance and operational costs. The model considers the microgrid designing problem over multi-year planning horizons. Figure 1 shows the schematic view of isolated microgrid designing problem.

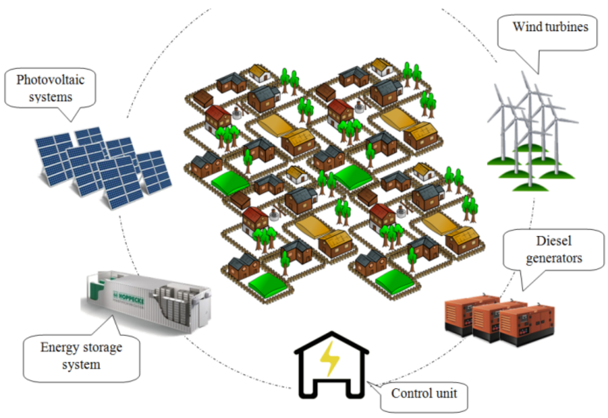

Fig 1. The schematic view of isolated microgrid designing problem

Objective function

This paper tries to minimize the total isolated microgrid initial investments including DG systems price and setup costs. Moreover, the DG systems annual maintenance and operational costs are considered as second expression in the objective function. Therefore, the objective function can be presented as below:

$$\text{Minimize } \sum_{i \in I} C_i.(PC_i + T.[PM_i + PO_i])$$

Where, I represents the set of DG systems (PV, WT, and diesel generators) and C_i denotes the capacity of DG i is applied in the microgrid network. PC_i, PM_i *and* PO_i show the initial investment (price and setup costs), annual maintenance costs (per kW) and operational costs (per kW per year) of DG i. Moreover, the model considers T-year planning horizons.

Reliability constraint

To measure the power system reliability, several indices namely SAIFI[1], SAIDI[2], ASAI[3], EENS[4], and etc. have been presented in the literature [7]. However, in this paper, to investigate a reliability concept, we used EENS index that is used generally in power generation units. EENS is defined as total energy that estimated is not being supplied in the isolated microgrid system. Therefore the EENS equation can be calculated as below:

$$EENS = \sum_{i \in I} \sum_{j \in J_i} P_{ij}.(\lambda_{ij}.LE_{ij}) \qquad (1)$$

Where:
J_i demonstrates the type of interruption in the DG i and P_{ij} is the probability of interruption j in DG i. λ_{ij} shows the rate of interruption in a year. Moreover, LE_{ij} presents the load curtailed for the interruption j in DG i. Therefore, in the reliability constraint, the maximum value of EENS must be less than a predefined value ($EENS_{max}$) and can be written in the following form:

$$\sum_{i \in I} \sum_{j \in J_i} P_{ij}.(\lambda_{ij}.LE_{ij}) \leq EENS_{max} \qquad (2)$$

Resiliency constraint

To improve the performance of isolated microgrid network in the disaster events, the model considered sets of resiliency constraints according to the using different DG systems. In this regard, for finding important critical events, resiliency factors were collected with the 50 experts' point of views and the results summarized in seven items. Each DG system is evaluated in the disaster events by using qualitative considerations. Furthermore, Table 2 presents the form in which the performance of DG systems and ESS in the disaster events is rated. As shown in Table 2, for each system in the network and according to the related critical event, the resiliency index (α_{ij}) is achieved based on the experts' opinion. In this regard, seven different types of exceptional incidents including Earthquake (more than 6 Richter), Flood, Severe storm, Heavy snow, Intense heat, Heavy rain, and Explosion were considered as disaster events in this study. However, to formulate the resiliency criterion, the capability of the network to supply the predefined

[1] System Average Interruption Frequency Index
[2] System Average Interruption Duration Index
[3] Average Service Availability Index
[4] Expected Energy Not Supplied

power over the different critical events is demonstrated. Additionally, to consider the power system resiliency, for each critical event, the model calculates the network resiliency index and proposes an unequal constraint. Therefore the resiliency equation can be calculated as below:

$$R_j = \frac{\sum_i \alpha_{ij}.C_i}{\sum_i C_i} \geq R_{j,min} \quad \forall j \in J \quad (3)$$

where α_{ij} shows the resiliency index of system i over the disaster event j and R_j presents the network resiliency over the disaster event j. Additionally, $R_{j,min}$ investigates the minimum predefined resiliency value must be achieved in the designing process.

Table 2. Evaluating DG systems and ESS under disaster events

Resiliency		DG (i) and ESS			
		Diesel generators	PV	WT	ESS
Disaster event (j)	Earthquake	$\alpha_{ij} \in \{1, 2, 3, 4, 5\}$			
	Flood				
	Severe storm				
	Heavy snow				
	Intense heat				
	Heavy rain				
	Explosion				
The system i total resiliency index		$\sum_j \alpha_{ij}$			

α_{ij}=1 Very low vulnerability
α_{ij}=2 Low vulnerability
α_{ij}=3 Moderate vulnerability
α_{ij}=4 Vulnerability and destruction with repair and reuse capability
α_{ij}=5 Extreme vulnerability and complete destruction

CASE STUDY: REMOTE VILLAGE IN TALESH CITY

In this paper, an isolated microgrid design problem is considered to supply the required power in Soubatan village in Talesh city (Figure 2). Soubatan is located in the mountainous region and approximately 36 kilometres distance from Talesh city. The village consists of 143 costumers with about 98 percent of residential customers. According to the experts' opinions, the isolated microgrid must supply 720kWh energy at the maximum peak value. Therefore, the total capacity of DG systems (Diesel generators, PV and WT) applied in the network must be appropriated to maximum peak value. However, in our study, the ESS is used for energy configuration in which power demand changes are occurring over a period as long as several hours, or shifting curtailed PV and WT production to later in the day.
To design the microgrid network, in the first step, the information about the initial investments and maintenance costs collected and investigated according to the Table 3.

Fig 2: The studied remote village in Talesh city

In this regard, three types of costs namely 1) price and setup cost, 2) annually maintenance cost, and 3) the system operational costs are considered in the designing process. Diesel generators use gasoil as fuel in the power generation process. Therefore, it is considered operational cost in the diesel generator systems.

Table 3. DG systems initial investment and maintenance and operational costs

	Price and setup costs (EUR per kW)	Annually maintenance (EUR per kW)	operational cost (EUR per kWh)
Diesel generators	80 €	175.2 €	0.112 €
PV	1150 €	0.12 €	0
WT	1250 €	24.75 €	0
ESS	250 €	34.3 €	0

To calculate the network reliability parameters, the wind speed and solar radiation data were investigated from 2014 to 2016 in 10 minutes intervals and diesel generators fuel shortage probabilities were calculated according to the critical events in the past 10 years. However, Figure 3 and Figure 4 show the summary of radiation and wind speed values in Soubatan village respectively. Furthermore, in the radiation and wind speed diagrams, the average values and the area within one standard deviation indicated at different times of day.

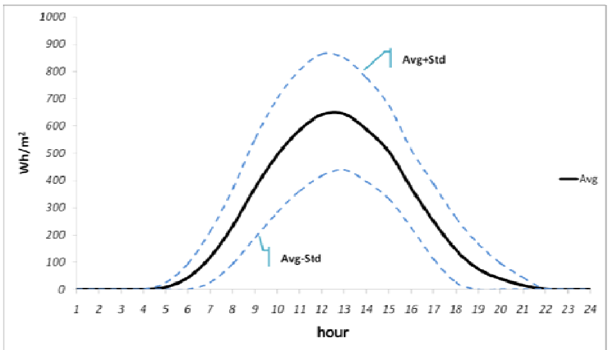

Fig 3. Summary of global radiation in the village

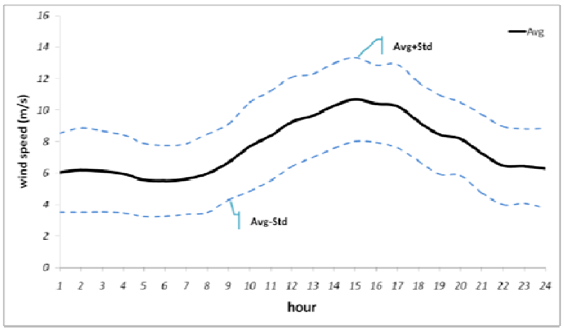

Fig 4. Summary of wind speed in the village

After calculating of input parameters, the related information was extracted from the experts´ opinion to collect and investigate the resiliency indices. In this regard, 50 experts graded the DG systems and ESS according to the seven disaster events. Table 4 presents the summary of resiliency index according to the experts´ opinion.

Table4. The resiliency indices of the network in the disaster events

Resiliency		DG (i) and ESS			
		Diesel generators	PV	WT	ESS
Disaster event (j)	Earthquake	3	3	3	2
	Flood	4	3	4	3
	Severe storm	2	4	4	2
	Heavy snow	2	4	2	2
	Intense heat	3	3	1	3
	Heavy rain	1	2	1	2
	Explosion	5	5	5	5
The system i total resiliency index		**20**	**24**	**20**	**19**
α_{ij}=1 Very low vulnerability α_{ij}=2 Low vulnerability α_{ij}=3 Moderate vulnerability α_{ij}=4 Vulnerability and destruction with repair and reuse capability α_{ij}=5 Extreme vulnerability and complete destruction					

After initializing input parameters and creating the model according to the objective function and reliability and resiliency considerations, the results showed approximately 80%, 13% and 7% of the estimated power must be supplied by diesel generators, WT, and PV respectively. However, the capacity of ESS is considered about 90 kWh energy according to the maximum value.

CONCLUTIONS

This paper investigated the isolated microgrid designing problem considering reliability and resiliency conditions. Indeed, unexpected and uncontroled events affect the microgrid production performance and increases the probability of vulnerabilities and interruptions in the electricity supply. Therefore, determination of interruption factors in the DG systems and optimizing microgrid structure considering reliability and resiliency stochastic parameters and initial financial investments improve the electricity production reliability in the microgrid according to the capital constraints. Moreover, to measure the reliability index, the EENS is considered as total energy that estimated is not being supplied in the isolated microgrid system and for the network resiliency constraint, the DG systems and ESS evaluation in the disaster events outlined according to the experts´ opinion. Additionally, the paper studied Soubatan village in Talesh city as case study for the proposed model implementation. Moreover, the results showed that diesel generators play an important role (more than 80%) in the power supplied system.

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