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A FRAMEWORK FOR ASSESSING THE DISASTER RESILIENCE OF SOLAR PV AND MICRO-HYDROELECTRIC TECHNOLOGY

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Abstract: In this paper, a framework for measuring the resilience of energy systems was developed. Based on previous literature in energy resilience, a four dimension model was generated (Robustness, Redundancy, Resourcefulness, and Rapidity). Each of these dimensions were further defined using key questions and indicators. Recommendations for quantifying each of the indicators were also provided.
Keywords: Renewable Energy, Disaster Resilience, Solar PV, Micro-Hydro.

INTRODUCTION

Solar (PV) and Micro-Hydroelectric (MH) energy systems are both considered eco-friendly and climate friendly technologies. For instance, hydropower on a small scale, or micro-hydro, is one of the most cost-effective energy technologies to be considered for rural electrification in less developed countries. It is also the main prospect for future hydro developments, where the large-scale opportunities either have been exploited already or would now be considered environmentally unacceptable (Paish, 2001). Aside from its cost effectiveness, hydropower also demonstrated reduction of gas pollutant emissions compared to fossil fuel-based energy systems supplying the same load (Kusakana et al, 2008).

Likewise, cost-effectiveness greenhouse gas reductions have been proven to be evident in solar PV systems (Heng et al, 2015). As further evidenced, manufacturing of solar PVs can be optimized to lead to a 71% reduction in its life cycle energy requirement (Mason et al, 2006). This further proves its environmental benefits not only in the actual energy production but as well as the energy required to reduce the solar PVs itself.

Recently, several challenges have been absorbed by proponents of the use of renewable energy systems in rural areas particularly in terms of financial and capacity related changes (Hong and Abe, 2012). Nevertheless, this does not contradict the fact that solar PV and MH systems are till the most economic and environmental energy systems today.

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Moreover, more than the intended benefit of climate change mitigation brought about by greenhouse gas reductions caused by renewable energy systems, the resilience of these energy systems from severe storms or other non-deal conditions which are mainly consequences of climate change (Leavitt and Kiefer, 2006; Neumann et al, 2015; Medina and Moraca 2016) should also be given emphasis (Panteli and Mancarella, 2015). As reported by the National Energy Laboratory (2014) the number of weather-related power disruptions has grown significantly within the past decade. Severe weather is now the leading cause of power outages in the United States. Sustained weather-related outages impact daily life, health and safety support services, communities, and the economy, with inflation-adjusted cost estimates of $18 billion to $70 billion per year, on average. Electricity associated with Hurricane Sandy (2012) are estimated to have resulted in $27 billion to $52 billion in economic losses from lost wages, spoiled inventory, grid damages, and sources. Thus it has been widely accepted that each of the alternative energy systems also has risks—some far less obvious than others (McLellan et al 2012). These risks include how it operates under non-ideal conditions brought about by disasters. In short, enhancing the grid resilience to extreme weather events is becoming of increasing interest (Panteli and Mancarella, 2015).

In general, resilience is very much interlinked with adaptive capacity and vulnerability (Matzenberger et al, 2015). There is however no consensus about the definition of resilience and how it could be measured and applied to improve electric power grids' performance during extreme events or other events, as it relates to its relevance within the aforementioned sociological context and, thus, applicable to customers in particular (Kwasinski, 2016). In this context however, resilience is defined as the ability of a power system to withstand extraordinary and high impact-low probability events such as due to extreme weather, rapidly recover from such disruptive events and absorb lessons for adapting its operation and structure to prevent or mitigate the impact of similar events in the future (Panteli and Mancarella, 2015).

However, quantifying the resilience of energy infrastructure systems is considered a complex process, and scales for measuring resilience—at any level—do not currently exist. Although having such scales would be useful in several ways (Bruneau et al, 2003). This paper fills this particular research gap. Although it doesn't provide the outright quantification method for measuring energy systems infrastructure resilience, it provides the needed insight as well as motivation geared towards that direction. In this paper, resilience is defined through an adaptation of the general concept of infrastructure resilience yet enhanced further to be applicable to energy systems through the determination of a contextual indicator system.

METHODOLOGY

The framework for assessing the resilience of solar PV and micro hydroelectric technology is based upon the models from previous studies (Bruneau et al, 2003; Kabalan & Anabaraonye, 2014). First, to operationalize the concept of resilience, the 4R dimensions of resilience were used as indicators (Bruneau et al, 2003, Tierney and Bruneau, 2007). These 4R refers to:

1. **Robustness**: strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function.
2. **Redundancy**: the extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality.
3. **Resourcefulness**: the capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis; resourcefulness can be further conceptualized as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals.
4. **Rapidity**: the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption.

However, the authors of the above dimensions did not specify exactly the quantification of the said concepts though they clearly emphasized the importance of such. Previous attempts to quantify were done I some literature in the country (Kabalan and Anabaraonye, 2014). In this particular study such quantification was not attempted but in a way provide basis for such, by finding the necessary literature to facilitate such quantification.

RESULTS AND DISCUSSIONS

Table 1 shows the framework for assessing the resilience of energy technology from disasters. Based on the framework below there are four dimensions of resilience being considered. This is called the 4Rs (Bruneau et al, 2003, Tierney and Bruneau, 2007) namely: Robustness, Redundancy, Resourcefulness, and Rapidity. Robustness refers to strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function.

Robustness is related both to the mode of the disaster and the physical location, materials, support structures, mode of operation and disaster defenses of the energy system. For example, solar photovoltaics are often roof-mounted, making them less vulnerable to flood damage but more vulnerable to high winds (McLellan, 2012). Robustness have been assessed in previous studies to describe the disaster resilience of PV systems (Fthenakis, 2013) and MH systems (Baidar, 2017). Previously also, robustness was used to compare PV amd MH systems in which PV is seen to be more robust due to its distributed nature (Kabalan and Anabaraonye, 2014).

Robustness is defined as strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function (Bruneau et al, 2003, Tierney and Bruneau, 2007). In this framework, it is thus important to take note that the key question to be used is “can the system withstand non-ideal conditions?”. This non-ideal conditions may refer to extreme weather events (i.e. flood, typhoon, etc.) (Fthenakis, 2013), or geologic events such as earthquakes (Baidar, 2017). Robustness can be quantified in terms of the strength of the structure depending on the type of disaster, this can be evaluated using simulation or other modeling techniques.

Table 1. Framework for assessing the resilience of Solar PV and MH Technology

RESILIENCE DIMENSIONS	Key questions	Indicator/s
Robustness	Can the system withstand non-deal conditions?	Non-Vulnerability from Disasters
Redundancy	Can the system components be easily replaced/repaired?	Simplicity of Civil Works Components Easy Access to Parts and Components
Resourcefulness	Does the management/maintenance of the system require a simple organization?	Simplicity of Organizational Structure
Rapidity	Can the system be replaced/repaired in the smallest possible time?	Shortness of Repair period

In terms of redundancy, this refers to the extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality (Bruneau et al, 2003, Tierney and Bruneau, 2007). In this framework, it simply asks the question “Can the system components be easily replaced/repaired?. Indicators for this dimension include Simplicity of Civil Works Components. A more complicated civil works such as forebay tank, spillway, penstock and power house (Prawin and Jawahar, 2017) is easily related to a lower redundancy because it may take a lot of effort to replace/repair the said system in case of damage from disaster. Quantification of this indicator requires a scale of measurement which assesses the complexity of the civil works needed in setting up the system.

On the other hand, although relatively connected, but still considered separate, another indicator for redundancy is in terms of the Easy Access to Parts and Components. This may refer to the availability of tools, equipment, and technical skills needed in the repair of the said system in case of damage from disaster. Presence of nearby shops, and technicians in the area is also an advantage in terms of this indicator (Kabalan and Anabaraonye, 2014). Though not directly considered as due to resilience, distance to repair services and spare parts is also regarded as a prime factor in the viability of an energy project especially those in rural areas (Barr 2013). Thereby, to insure a higher redundancy, project managers can opt for stocking of critical parts that have long supply lead times so that the system is not left offline because of a lack of spare parts (Hatti, 2014). This indicator can be quantified using a Likert Scale dependent upon the degree of ease that parts and components can be replaced.

Resourcefulness on the other hand refers to the capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis; resourcefulness can be further conceptualized as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals (Bruneau et al, 2003, Tierney and Bruneau, 2007). In the framework this is simplified through the key question “Does the management/maintenance of the system require a simple organization?”. The main indicator for this dimension is Simplicity of Organizational Structure. A system that requires a simpler form of organization to run and maintain is preferred over a system that requires more complicated managerial and technical skills (Kabalan and Anabaraonye, 2014). In the event of a disaster, logistics support may be scarce which is equivalent to the lack of human resources to manage a system. However a simple organizational structure is easier to set up in the shortest possible time especially in non-ideal situations this making it more resilient. The quantification of this indicator can be in terms of the degree of simplicity of the organizational structure needed to manage the system. A Likert Type Scale can be used to measure this.

Rapidity refers to the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption (Bruneau et al, 2003, Tierney and Bruneau, 2007). In this framework it answers the key question of “Can the system be replaced/repaired in the smallest possible time?”. The basic indicator for this dimension is Shortness of Repair period. Solar PV systems are known to have a quicker repair time (Fthenakis, 2013) than MH systems (Baidar, 2017) regardless of the type of disaster. In the framework, this indicator can be quantified in terms of the maximum time required to repair a major damage in the system so that it can be able to supply power back to normal.

CONCLUSIONS

In this paper, a framework for assessing the resilience of solar PV and MH systems was developed. The framework is based on the dimensions of Robustness, Redundancy, Resourcefulness, and Rapidity. Based on the above dimensions, key questions as well as indicators were identified to better define the concept of resilience for the said energy systems. Furthermore, quantification methods were suggested to facilitate a more objective means of evaluating resilience of the abovementioned energy technology systems.

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