STANDARD OPERATING PROCEDURE FOR DEVELOPMENT OF ADAPTIVE RESILIENCE CURVE TO ASSESS RESILIENCE OF CLEAN ENERGY SYSTEMS

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ABSTRACT

Quantification of resilience is crucial for monitoring evaluating performance of energy systems. Several past studies attempted to quantify adaptability and resilience while findings do not yet lead to mathematical quantification and practical application. Our previous study conceptualized adaptive resilience curve for this purpose, though its applicability has not been demonstrated. Therefore, this study aims to review adaptive resilience curve proposed in the previous study to extract key elements which used to build the adaptive resilience curve, and to develop a standard operating procedure based on the key elements. Since the curve adopted adaptive attributes from three concepts, including global catastrophic risk, beyond design basis accident, and foresight, the standard operating procedure consists of step-by-step instructions corresponding to each concept. The procedures for global catastrophic risk emphasized identifying a target disruptive event based on historical record and determining figures-of-merit to cover variety of transition functions. The procedures for beyond design basis accident involved determining actions to address the disruptive event by mitigating the disruption or quicken the recovery, and comparing the function with and without the actions to understand their effectiveness. The procedures for foresight aimed at investigating possible scenarios for function variations. The developed standing operating procedure resulted in four line graphs to visualize transitions of functions throughout a period of time. This study shows that the standard operating procedure can guide practitioners to construct case-specific adaptive resilience curves based on the local context of systems. The adaptive resilience curve offers a clear picture of how a disruptive event affects the operation of clean energy systems and how a measure alleviates the impacts of system disruption.

Keywords: Adaptability, Standard operating procedure, Global catastrophic risk, Beyond basis design, Foresight

I. INTRODUCTION

Climate adaptation has grown rapidly in response to climate change impact. Globally, progress in the pursuit of climate adaptation draws attention among high-risk countries in which it is believed to enhance adaptive capacity, strengthen resilience, and reduce vulnerability [1]. Quantification of adaptability and resilience becomes crucial for monitoring and evaluating the performance of energy systems. Several past studies attempted to address the question yet found to rely on investigating a set of characteristics needed for resilience [2], measuring delivery function for transition [3], exploring adaptation options [4], and engaging decision making to provide climate change responses [5]. In order to quantify adaptability and resilience in energy systems, there is a need for methodological frameworks to measure time dependent characteristics of events and capture changes which occurred after the events and actions applied to address the impact. The previous study [6] proposed a concept on adaptive resilience curve which was theoretically conceptualized to quantify adaptability of systems. The adaptive resilience curve is an event-based and time dependent metric for resilience. The adaptive resilience curve attempted to capture adaptability in which it was constructed of a delivery function for transitions in resilience proposed by Henry and Ramirez-Marquez [3] and introduced contributions of global catastrophic risk, beyond design basis accident, and foresight in order to capture the adaptability. Originally, the delivery function for transitions in resilience quantifies resilience of systems in a time dependent metric. By integrating the contributions, the adaptive resilience curve quantifies adaptability of systems in an event-based basis. Yet, the concept of adaptive resilience curve was developed and proposed, applicability of the adaptive resilience curve was not demonstrated.

To demonstrate the applicability of adaptive resilience curve with a system, there is a need for a procedure organized to maintain consistency, efficiency, and quality across the practice. A standard operating procedure, referred to as a set of step-by-step instructions organized to guide practitioners carrying out complex routine tasks [7], can be utilized to assist in conducting the adaptive resilience curve. According to the previous study, the adaptive resilience curve is not only difficult to conceptualize but also difficult to conduct in rigorous and mathematical manners. Since the adaptive resilience curve has a delivery function for transitions in resilience as its foundational principle and is integrated with global catastrophic risk, beyond design basis accident, and foresight, the standard operating procedure should be developed to guide practitioners throughout each key elements of the theories. The adaptive resilience curve should be reviewed to extract the key elements in order to systematically design the standard operating procedure. Thus, the objective of study is to review adaptive resilience curve proposed in the previous study to extract key elements which used to build the adaptive resilience curve, and to develop a standard operating procedure based on the key elements.

II. METHODOLOGY

This study employs a methodology to review adaptive resilience curve proposed in the previous study [6] to extract key elements which are used to build the adaptive resilience curve, and to develop a standard operating procedure based on the key elements.

In order to review the adaptive resilience curve to extract key elements, a fundamental idea of conceptualizing the adaptive resilience curve needs to be investigated. The fundamental idea of adaptive resilience curve consists of contributions of global catastrophic risk, beyond design basis accident, and foresight. Mentioned in scholarly works [8], information extracted from the contributions can be utilized to structure the standard operating procedure. The scopes of the contributions are included: contribution of global catastrophic risk involves identifying target disruptive events and determining proper figures-of-merit to exhibit the disruptive events based on historical record. Contribution of beyond design basis accident involves determining actions (measure) to address the target disruptive events and comparing function with and without the actions. Contribution of foresight involves investigating possible scenarios for function variations.

In order to develop the standard operating procedure for conducting the adaptive resilience curve, it is important to provide a set of written instructions that outline steps for performing tasks to produce the contributions. Each contribution has its own set of instructions to ensure consistency.

III. RESULT

This section presents results from review of adaptive resilience curve and its key elements, and standard operating procedure for conducting adaptive resilience curve. The review of adaptive resilience introduced contributions of global catastrophic risk, beyond design basis accident, and foresight, respectively to extract key elements. The standard operating procedure is developed based on the contributions introduced in the previous section. The set of instructions outlines steps for performing tasks to produce each contribution.

III.A. Review of adaptive resilience curve and its key elements

The adaptive resilience curve was built upon the delivery function for transitions in resilience, which is a time dependent metric for resilience. The metric is mathematically quantified to assist in computation of resilience in systems, time for resilience, and total cost in resilience improvement. The adaptive resilience curve was conceptualized by integrating the contributions of theories including global catastrophic risk, beyond design basis accident, and foresight. The essence of ideas to integrate the theories is to improve the delivery function for transitions in resilience in order to mathematically quantify adaptability of systems in a time dependent basis. To quantify adaptability of systems, variety of functions, function transitions, alternative scenarios of a function transition are needed to access. The sub sections below discuss how variety of functions, function transitions, alternative scenarios of a function transition are derived from the contributions of global catastrophic risk, beyond design basis accident, and foresight, respectively

III.A.1. Contribution of global catastrophic risk

Global catastrophic risk in general characterizes severity of risks into scales and dimensions using variables including scope, intensity, and probability. To assess the variety of functions, the variable of scope was utilized to investigate scope of risks perceived by systems. The scope of risks determines a function ($F(t)$), transition on a time dependent basis is assessed and translated into a level of resilience. In this sense, the scope of risks is utilized to explore risks and reflects resilience of systems in different aspects. Thus, the key element for the contribution of global catastrophic risk is function variation derived from scopes of risk.

III.A.2. Contribution of beyond design basis accident

Beyond design basis accident emphasizes a set of actions: preventing the escalation of an event into a severe accident, mitigating consequences of a severe accident, and achieving a long-term safe stable state, to address impacts on systems. System functionality is transitioned when an event occurs, and an action applies. Transitions derived from an event are assessed by the scope of risks, transitions derived from an action are assessed by action effectiveness. In this sense, it is important to know how an action contributes to function transitions. Thus, adaptability of systems is perceived as differences between the transition derived from an event and the transition derived from an action. The key element for the contribution of beyond design basis accident is function transitions derived from a set of actions.

III.A.3. Contribution of foresight

Foresight is known as a systematic approach to translate and interpret information for alternative scenarios and futures. In a function transition, there is a possibility of a variety of scenarios derived from an event. Foresight plays a key role in depicting alternative scenarios of a function transition using available information to translate and interpret. In adaptive resilience curve, transitions derived from an event and transition derived from an action can be foresee for alternative scenarios. Thus, the key element for the contribution of foresight is alternative scenarios of a function transition depicted by foresight.

III.B. Standard operating procedure for conducting adaptive resilience curve

The standard operating procedure is developed based on the abovementioned key elements including scope of risks, a set of action, and alternative scenarios. In order to produce the contributions, the following sub sections outline steps for performing necessary tasks.

III.B.1. Instructions for function variation derived from scopes of risk

1. Select an event to investigate function variation
2. Determine time window for the event
3. Set up a function ($F_0(t_x)$) to be assessed as a baseline function
    a. Determine $F_0(t_0)$: status at the beginning of the time window
    b. Determine $F_0(t_e)$: status at the initiation of the disruption
    c. Determine $F_0(t_d)$: status at the initiation of the disruptive state
    d. Determine $F_0(t_s)$: status at the end of the disruptive state
    e. Determine $F_0(t_f)$: status at the beginning of the stable recovered state, and
    f. Determine $F_0(t_a)$: status at the beginning of the adaptive state, if any.
4. Create a line graph of the determined function ($F_n(t_x)$) using available data.
    a. The determined function ($F_n(t_x)$) is represented as Y-axis, and the time window is represented as X-axis.

III.B.2. Instructions for function transitions derived from a set of actions

It is important to note that this set of instructions is only performed when an action is applied and instructions for III.B.1. is completed.

1. Determine time window for the action implementation
2. Determine one function ($F_{n,r}(t_x)$) to be assessed as an action function
    a. The function ($F_{n,r}(t_x)$) must have an identical nature to the function ($F_0(t_x)$)
3. Create a line graph of the determined function ($F_{n,r}(t_x)$) using available data.

   a. The determined function ($F_{n,r}(t_x)$) is represented as another Y-axis, and the time window for action implementation is represented as X-axis.
4. Integrate the determined function ($F_n(t_x)$) and function ($F_{n,r}(t_x)$) into a line graph and use time window for action implementation
5. Compare differences between the determined function ($F_n(t_x)$) and function ($F_{n,r}(t_x)$)

III.B.3. Instructions for alternative scenarios of a function transition depicted by foresight

It is important to note that this set of instructions is only performed when instructions for III.B.2. is performed.

1. Study the selected event from external sources of information
   a. Gather information for possible function transitions including a range of small to large severity of impacts, cascading impact, a range of short to long time of disruptions
2. Integrate outputs from the gathered information into the determined function ($F_n(t_x)$), and determine as an alternative scenario of determined function ($F_n(t_x)$)
3. Study the implemented action from external sources of information
   a. Gather information for possible function transitions including varying speed and target of transition.
6. Integrate outputs from the gathered information into the determined function ($F_{n,r}(t_x)$), and determine as an alternative scenario of determined function ($F_{n,r}(t_x)$)
7. Create a line graph for the alternative scenario of determined function ($F_n(t_x)$) and the alternative scenario of determined function ($F_{n,r}(t_x)$)

When completed III.B.1, III.B.2, and III.B.3, a total of four line graphs, as shown in Fig.1, are generated including:
1. Determined function ($F_n(t_x)$) represents function transition when the selected event occurred.
2. Determined function ($F_{n,r}(t_x)$) represents function transition when the selected event occurred and the implemented action applies.
3. Alternative scenario of determined function ($F_n(t_x)$) represents possible transition when the selected event occurred.
4. Alternative scenario of determined function ($F_{n,r}(t_x)$) represents possible transition when the implemented action applies.

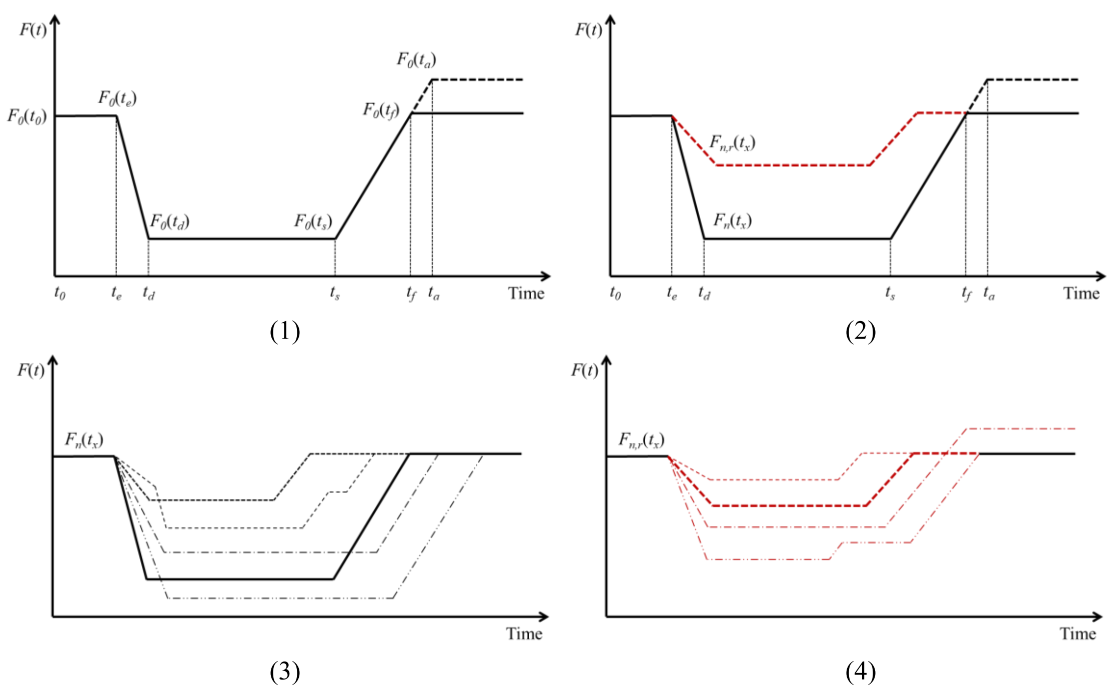

FIGURE 1. graph representations as outputs of standard operating procedure

The adaptive resilience curve is a mathematical approach assisting users in computation and quantification of the adaptability of systems. The outputs can also visualize transitions of a function under various conditions of systems. The standard operating procedure provides flexible use to practitioners in response to specific needs. Conducting adaptive resilience curve is an iterative process in which practitioners decide which insight or interpretation is necessary to fulfill the specific needs and sets of instructions can be performed iteratively. In order to investigate further variation of transition and time window, instructions for function variation derived from scopes of risk can be repeated. To compare differences in the implemented actions, practitioners follow instructions for function variation derived from scopes of risk and instructions for function transitions derived from a set of actions. To foresee other alternative scenarios, repetitive completion of instructions for alternative scenarios of a function transition depicted by foresight alone is an option.

IV. DISCUSSION

The adaptive resilience curve is developed to quantify the adaptability of systems through investigating function transitions after an occurrence of events and implementation of actions. In a certain sense of resilience improvement, the adaptive resilience curve acts as a tool to visualize function transitions and quantify effectiveness of actions, which are interpreted as resilience improvement. The investigation of function transitions does not only visualize impact on systems and effectiveness of actions but also indicates how exposed systems are against events. This implicit finding reflects current conditions of a system and creates awareness for stakeholders to make decisions. It signifies urgency to improve resilience in systems. It is important to note that actions implemented to address impact on systems should be central to reduction of severity, occurrence, and time of impact. Since severity, occurrence, and time of impact are the primary aspects which resilience is central on, actions to pursue the aspects are expected to contribute to the adaptability of systems. Suitability of an action is determined based on current conditions of a system and how urgent the actions need to be.

The standard operating procedure for conducting adaptive resilience curve is developed based on the key elements extracted from the contributions of global catastrophic risk, beyond design basis accident, and foresight. Three sets of instructions are developed and contribute to a total of four line graphs for further discussion. It is important to note that instructions for function variation derived from scopes of risk and instructions for function transitions derived from a set of actions require extensive data generated or gathered from the system. Availability of data before an event occurs until an action applies is crucial to the instructions. Further research and study on alternative scenarios of the selected event and implemented action depicted by foresight require sufficiently detailed data. Thus, this can imply that success of adaptive resilience curve is based on availability of data.

V. CONCLUSION

This study has objectives to review adaptive resilience curve proposed in the previous study to extract key elements which used to build the adaptive resilience curve, and to develop a standard operating procedure based on the key elements. The finding on review of adaptive resilience curve indicates that the delivery function for transitions in resilience is the fundamental principle of the adaptive resilience curve, which is a time dependent quantifiable metric. In order to equip with an ability to quantify adaptability of systems, contributions of theories including global catastrophic risk, beyond design basis accident, and foresight were integrated. The key elements adopted from the contributions consist of variety of functions, function transitions, alternative scenarios of a function transition, respectively. The key elements play a crucial role in investigating adaptability of systems through considerations of scope of risks, a set of actions, and alternative scenarios of event and action.

The study develops the standard operating procedure for conducting adaptive resilience curve by utilizing the key elements of contributions. The standing operating procedure consists of three sets of instructions including instructions for function variation derived from scopes of risk, instructions for function transitions derived from a set of actions, and instructions for alternative scenarios of a function transition depicted by foresight. Each set of instructions is developed to produce identical contributions to global catastrophic risk, beyond design basis accident, and foresight. As a result, the standard operating procedure guides to four line graphs: function transition when the selected event occurred, function transition when the selected event occurred and when the implemented action applies, possible transition when the selected event occurred, and possible transition when the implemented action applied. When the line graphs are interpreted implicitly, the finding contributes to current conditions of a system against an event, effectiveness of actions applied to the system, and possible transitions of the event and action. Thus, the standard operating procedure can lead to quantification of adaptability of systems which can be perceived by numeric differences between function transition when the selected event occurred and when the implemented action applies.

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