Project Proposal on the Design of How Earthquake Proofing of the National Power Grid can be improved

Group 26

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1 Abstract

Earthquakes pose a threat and are a massive problem that humanity faces in the 21st century. Many countries, such as Turkey and Japan, have experienced devastating earthquakes that resulted in the destruction of structures and the loss of lives. Our project proposal is to design a practical strategy to enhance earthquake-proofing within the power grid and give some suggestions to improve the current systems. This report includes a justification to demonstrate our capacity to develop effective earthquake-proofing techniques for the national power grid.

2 Project Topics and Goals

2.1 Project Topics

Our proposal aims to identify the vulnerabilities of power systems during an earthquake and provide solutions in the form of resistant components to combat the effects such a disaster has on people and countries. To identify the weak points in a power system, we plan to conduct our experiments and combine the findings with data from recent earthquakes to form a holistic perspective of the problem.

Due to the modern world's dependency on power, it has become increasingly necessary to protect the systems that distribute it. The dependency is only heightened in the aftermath of an earthquake, where the response can be divided into two main categories: short and long-term. Short-term issues are concerned with the days and weeks after an earthquake and are the most vital when it comes to preserving life. Hospitals become overwhelmed and rely on power to treat the injured, refrigerate medication and communicate with emergency services. The ability to access power could be the difference between life and death during a rescue mission where tools and machinery are needed to remove heavy debris.

Effects felt years or even decades after the earthquake are considered long-term and mainly concerned with repairing and rebuilding damaged infrastructure. Suppose the power grid was robust enough to withstand the seismic activity. In that case, years may be knocked off the redevelopment process. The financial resources saved can be allocated to other areas of the recovery effort, elevating some of the financial burdens on an already resource-stretched government.

Vulnerabilities of electrical power systems to earthquakes affect both developed and developing nations, with disruptions in power distribution observed even in the USA, considered one of the most advanced and earthquake-conscious countries in the world. Complex power systems are expensive to replace, and the components that make up their structure tend to be more fragile, exposing a developed nation to the financial implications of an earthquake.

The nature of earthquakes means they are unpredictable and unstoppable. Our research will then focus on the mitigation of the problems that arise in the wake of an earthquake with the aim to be integrated into the developing world. Although many civil engineering approaches to this problem exist, they are costly to implement and are often difficult to fit retrospectively. Our proposal will look to be a cheaper alternative to these traditional mitigation strategies while offering an upgrade to outdated systems that are often found in developing countries.

2.2 Goals

- Identify the vulnerabilities in power grids
- Develop solutions in the form of resilient components
- Cost effective end product to ensure applications in the developing world

3 Topic Selection and Discussion Process

3.1 Topic Selection

When discussing possible topics for the project, we used current world events to draw inspiration. At the time Turkey had just been hit by a magnitude 4.6 earthquake, with the aftermath being widely documented. We had a discussion and researched how we could apply the knowledge from our degrees to help aid this situation and identified the issue of power as one we could help with. Data form the 2008 Wenchuan earthquake in figure 1 shows how power grid load is effected by earthquakes

Area	Pre-earthquake Load (million kilowatts)	Post-earthquake Load (million kilowatts)	Electric Load Loss (percentage)
Chengdu	3.06	1.07	65
Deyang	1.07	0.11	90
Mianyang	0.56	0.01	98
Guangyuan	0.39	0.08	79
Aba	0.09	0.00	100

Fig. 1 Power Grid Load Loss Table from the Wenchuan earthquake

We investigated the frequency of earthquakes to determine the viability of addressing this issue. It is imperative to assess whether dedicating time and resources to a research project on earthquakes would yield significant benefits compared to other potential research topics.

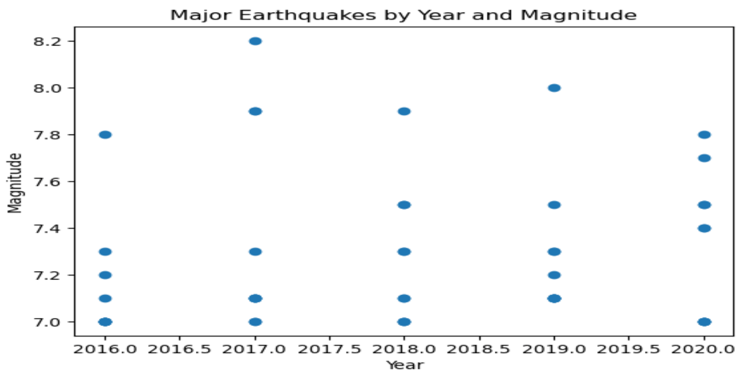

Fig. 2 Major Earthquakes From 2016 to 2020

Fig 2 shows a scatter plot of major earthquakes by year where each dot represents a country. As shown by the figure, there has been a high amount of major earthquakes over the last eight years alone, each displaying, potentially billions of pounds in damage and countless deaths and injuries to people.

We also discussed the idea of research into electric vehicles which initially we were very attracted to due to the vast applications our degrees had to this topic. It is well known that the transition from the traditional combustion engine to electrical motors within the motor vehicle industry is very much underway, being part of research in an emerging industry added to the attractiveness of this topic. However a valid point was made, that compared to giant corporations with access to billions of dollars and seemingly endless resources , could a team of 6 undergraduate students realistically make a notable contribution to this topic of research. Additionally the broad of this topic would mean that instead of working on a full 'car', the project would likely involve specific components, such as sensors which seemed far less glamorous.

3.2 Discussion Process

3.2.1 Choosing topic

To decide on a more specific project proposal we used multiple criteria decision analysis (MCDA). The benefit of using this strategy to decide on our topic is because the MCDA table, allows for a systematic and structured approach to evaluating all the options we have brainstormed and rank them based on their individual criteria marks based on their weightings. Below, labelled as Fig 3, is the MCDA table we have formulated with the specific rankings of the criteria, Fig 4 . and the weightings of the criteria Fig 5 .

		Power Grid		Power Stations		Dependancy		Evs		Entire National Grid	
	Weighting	Score (1-5)	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Criteria:											
Practicality	10	5	50	3	30	4	40	4	40	4	40
Previous Work Done	6	5	30	5	30	5	30	4	24	5	30
Technicality	4	3	12	3	12	2	8	5	20	3	12
Relevance	8	3	24	4	32	2	16	5	40	4	32
Usefulness	7	4	28	5	35	4	28	5	35	4	28
Scope	9	4	36	3	27	5	45	1	9	2	18
Cost	5	2	10	1	5	4	20	1	5	1	5
Total	245		190		151		187		173		165
% of Total			77.6		61.6		76.3		70.6		67.3
Rank											

Fig. 3 Data Tabulated onto a Multiple Criteria Decision Analysis Table

Function		A	B	C	D	E	F	G
Practicality	A	-	A	A	A	A	A	A
Previous work done	B	-	-	B	D	E	F	G
Technicality	C	-	-	-	D	E	F	G
Relevance	D	-	-	-	-	D	F	D
Usefulness	E	-	-	-	-	-	F	G
Scope	F	-	-	-	-	-	-	F
Cost	G	-	-	-	-	-	-	-

Fig. 4 Table displaying the criteria and how we have decided to rank them

Letter	Total	Weighting
A	6	10
B	1	6
C	0	4
D	4	8
E	2	7
F	5	9
G	3	5

Fig. 5 Table of values corresponding to the Weightings

To begin with, by observing Fig 4, we have listed, below the 'Function' heading, what we think, the essential criteria are when deciding what we choose for our proposal. Let us take the criterion, 'Practicality', for example. This criterion will refer to how realistic and possible it would be to implement this in real-world situations and how possible it would be as a project for next year, which is considered the main aim of our project proposal. Additionally, looking more into the practicality criterion, it takes a higher ranking than all the other criteria listed, as can be seen where A is prioritised over B, C, D, E, F, and G. A different example of the following rankings and how they work, can be if we focus on the criterion, 'Previous work done' it has a higher ranking than C, ' Technicality', but does not prioritise over criterion D which would be 'Relevance'.

Moreover, if we shift the focus to Fig 5, we have given the letters corresponding to their criterion the following weightings based on what we have decided should get the highest weighting. For example, as criteria A, relating to the practicality of the proposal has the highest ranking above all other criteria, it deserves to have the heaviest weighting of the value ten. The lowest weighting of value four was given to criteria C, 'Technicality', as it did not appear anywhere on the table in Fig 4 as it did not outrank any other criteria making it the least important but still relevant within our decision making process hence why it deserves a weighting.

After covering how the ranking and weightings of the criteria were formulated, we can now analyse the results in Fig 3 where we scored the ideas from one to five and multiplied the score by the weightings to allow for a final sum of the criteria to be made to display a final value in the ' % of Total' row that can be compared to the other numerical values on that row. An idea's max weighting would be 245 if all criteria were scored a 5. Focusing on the idea of the Power grid, transmission towers, and how they could be positively adapted to be earthquake proofed, we gave a practicality score of 5 which led to a weighting of 50. We gave this a max score based on the resources we have available at Bristol, such as an earthquake lab. This idea is extremely practical, as we can run experiments such as Shake-Table or Pseudo-dynamic testing, which will provide us with very accurate results if we decide to pursue this project. [1] Based on the work previously done, we decided to give this criterion a max score of 5 as there are several online resources on how earthquakes affect these transmission towers and power grids. Extensive research into bettering the systems is available across the internet, making this idea possible. However, the lowest score regarding the power grid idea was given to the 'Cost' criterion, value 2, as this in the future would be a high-cost project, for example, if we wanted to test materials and power systems such as a transformer to improve the power grids during an earthquake we would have to buy these materials to get accurate experimental data. The final percentage of the score was 77.6%. This process of scoring the project proposal idea was repeated across the other four ideas to allow for comparison to choose the final idea.

3.2.2 Decision

When deciding what project proposal idea to pick, we focus on Fig 3 again and look across the '% of Total' row where we can compare all values based on the sum of their weightings as a percentage of the max score they could have got. The idea of power grids gave the highest percentage of 77.6% allowing us to choose this idea confidently with a close score of 76.3% coming in next under dependency.

4 Experimental and Technical Specifications

4.1 Experimental Methods

In this section on experimental methods, we delve deeply into exploring the feasibility and cost-effectiveness of various materials and techniques that can bolster the structural integrity of the power grid, ensuring uninterrupted system operation. As a group, we must consider, for example, whether the current approach to protecting the power grid can be improved through testing. Simulations can be conducted for the components that we plan to construct. Regarding physical experimentation, we can leverage our Earthquake and Large Structures Laboratory, which can facilitate two potential experiments:

1. Shake-Table Testing: A large shake table that has the ability to generate seismic waves by moving horizontally and vertically to simulate the ground motions that occur during an earthquake. Structures acting as a transmission tower, for example, can be attached to this table, built with various materials to test which material is the strongest.

2. Pseudo-Dynamic Testing: Applying simulated earthquake forces using hydraulic actuators to the experimental structure to see how well it sustains the seismic forces.

4.2 Technical Specifications

This section presents an introduction to three main software tools that are publicly accessible and designed for earthquake analysis on computers or laptops. The tools are as follows:

1) Earthquake simulation tool:

This 'rWHALE' tool is primarily developed in the C++ programming language and requires Building Information Model (BIM), Hazardous Events (EVENT), Structural Analysis Model(SAM), Engineering Demand Parameters(EDP) and Damage and Loss(DL) files to simulate an earthquake. By providing this data and executing the scripts, this tool can produce simulation data, which enables the prediction of the causes of earthquakes based on the simulation data.

a.Building information model (BIM): Information on the power grid's dimensions, materials, location, etc.

b.Hazardous events affecting the building (EVENT): Both natural and human-made factors that could affect the building and its integrity.

c.Structural analysis model (SAM): A model of the power grid's overall structure.

d.Engineering demand parameters (EDP): Information on the construction process of the power grid.

e.Damage and loss (DL): Data on the negative impacts of an earthquake on the power grid.

2) Earthquake detection tool:

The REDPy' (Repeating Earthquake Detector in Python) tool is an automated detection and analysis tool designed to detect repeating earthquakes in continuous data. Developed using the Python programming language, the tool can be configured and installed on a computer or laptop to detect earthquakes. When an earthquake is detected, the tool produces an alarm and waveform diagrams and stores all the data for viewing in the event of subsequent earthquakes.

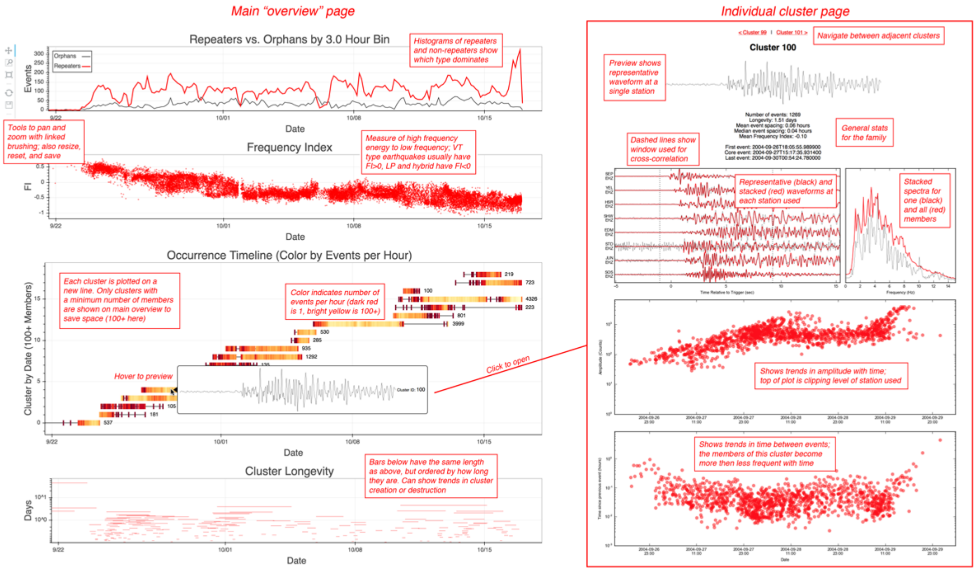

Fig. 6 Annotation

3) Earthquake analysis tool:

The earthquake analysis tool, named 'BEAT', is a Python-based software that requires access to the internet and specific information related to the location of the power grid, such as latitude, longitude, elevation, and depth. This tool analyzes earthquake data fed into it by researchers, producing analysis data, summary plots, and animations of the earthquake. By utilizing real-world earthquake data, BEAT can assist in determining the causes and mechanisms of an earthquake, aiding in the prediction of future occurrences and enabling better methods of safeguarding power grids in the future.

```
#network_name.station_name.location_name latitude[deg] longitude[deg] elevation[m] depth[m]
IU.TSUM.10             -19.20220       17.58380        1260.0          0.0
  BHE            90              0              1   # channel name azimuth[deg] dip[deg] gain \n
  BHN             0              0              1
  BHZ             0            -90              1
IU.RCBR.00              -5.82740      -35.90140         291.0          109.0
  BH1            48              0              1
  BH2           138              0              1
  BHZ             0            -90              1
...
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Fig. 7 Snip

5 Project Planning

5.1 Gantt Chart and Timeline

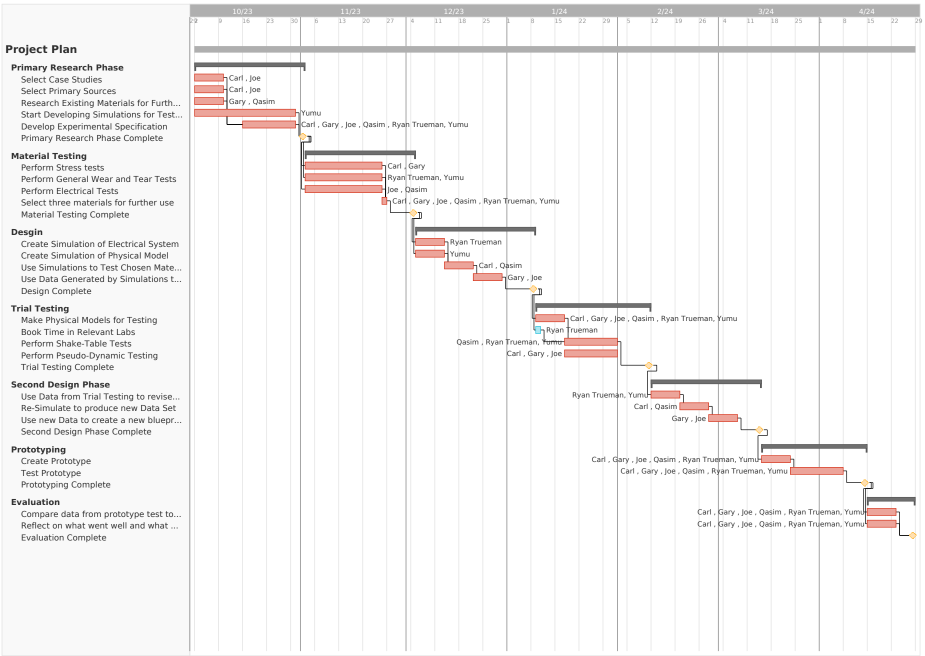

Fig. 8 Gantt Chart

Fig 8 shows the gantt chart plan for project, with red tasks being tasks on the critical path.

5.2 Project Roles

Qasim Sheikh Second Design Phase Plant EEE Student	Carl Blastique Primary Research Phase Resource Investigator EEE Student	Gary Xue Trial Testing Phase Monitor Evaluator EEE Student
Ryan Trueman Project Manager & Material Testing Shaper EEE Student	Yumu Xie Design Phase Plant CSE Student	Joe Taylor Prototyping Completer Finisher EEE Student

6 Problems of Project

There are some potential problems we need to deal with or fix in our project proposal:

1. This proposal is entirely theoretical which means all information and data found was sourced from the Internet. Therefore these information we searched are outdated, which there is no field research we really have done to design this project, though it can be a reference for people to predict earthquakes in future. The proposition was not conducted physically. For instance, travelling to earthquake-prone regions to gather real phenomenon data, simulating real-world earthquakes in various sample geographical locations in the civil engineering lab, and examining the effects that various earthquake magnitudes may have. Conducting more physical experiments to supplement the theoretical information gathered from the internet will allow you to gather much more up-to-date information and will also lend more credibility for the proposal.

2. We did not research extensively lot on real-world physical representations of power systems in various nations. Power grids in the actual world are entirely different compared with the theoretical models. Since all of the data and information we gathered came from the Internet and theory rather than actual experience and tangible evidence, the outcomes could vary. Conducting more physical experiments to supplement the theoretical information gathered from the internet will allow you to gather much more up-to-date information and will also lend more credibility to the proposal.

3. Our project's scope slightly exceeds that of our original. Our idea is overly comprehensive yet not entirely precise. The techniques we employed to improve the earth-quake proofing ability are too idealistic. They take place in an ideal setting, but we failed to take into account practical considerations. For example, governments may not wish to invest money in enhancing the earth-quake proofing of their region as they may choose to spend more money elsewhere such as global issues on global warming. Narrowing the project scope to focus on more specific and realistic methods for improving earthquake-proofing of power grids will require focusing on a specific region which has a high rate of earthquakes.

7 Risk Assessment and Possible Solution

The risk for our project is made up of 5 categories

1) Technical risks, mainly related to code bugs and equipment failure

2) Safety risks, the risk related to members' health.

3) Regulatory risks, this risk is caused by the inability to purchase or use a certain material.

4) Operational risks, we should consider the risk of power outages, blackouts, and other disruptions such as natural disasters.

5) Supply chain, the possibility of delays or shortages in the delivery of equipment and materials should be considered.

The majority of those risks will cause a delay in the project. A few days should be left between the two tasks to prepare for the delay. The missing of a structural engineer is a serious problem it might cause the project cannot carry on. Safety rules should be set up when members are doing tests for the materials and structures. The chance for members to get injured will be decreased.

Type of Risk	Description of Hazardous event	Description of Consequence	People possibly at risk	Mitigation(s)	Risk Leve			Risk Leve		
					Frequency	Consequen ce	Residual Risk	Frequency	Consequen ce	Residual Risk
Project	Missing someone who is knowledgable in Civil and material engineering	May not be able to complete design of mode or may delay the process.	Project success is at risk	Before the project find team memebrs with the correct skillsets needed	5	5	25	3	5	15
Technical	Model falling apart during the shaking table test and the field test.	Caun cause injury or death.	Anyone in the lab	Check the lab safety rules before going to the lab. Make sure everyone is a safe distance when testing.	3	5	15	2	5	10
Project	Going beyond planned time for design and creating model.	Project could have increased costs, delayed delivarables and project may be terminated.	Project success is at risk	Alter scheduling of tasks depending on circumstances in order to make the deadline.	3	3	9	3	2	6
Project	Deliver delay of materials needed for the making of the model.	Delays project and can increase costs.	Project success is at risk	Order the equipment earlier so delays do not affec the project completion.	4	2	8	4	1	4
Technical	The model's size and weight is over the max limit set.	Causing damage to the testing equipment	Project success is at risk	Check lab limitations before designing and creating model	2	4	8	1	4	4
Technical	High voltage cable used when testing	May cause death or potential fire which could not only affect the lab but also the building.	Everyone involved in the test. The workers, lab technicians, tourists from the public in the building	All people in the lab must wear safety kit and handle any high voltage cables with caution	4	5	20	2	4	8
Operational	Unable to use lab on the day which originally planned	Causing a delay on project	Project success at risk.	Pre-book lab sessions to ensure availability of labs.	4	4	16	1	4	4
Technical	Losing the simulation data	Cauing a delay for the simulation part and code must be rewritten before it can be tested.	Project success is at risk	Constantly back up data to a cloud drive and or USB stick.	3	3	9	1	3	3
Operational	Natural Disasters	Natural disasters such as earthquakes and flooding can prevent us from accessing the lab hence dealying the project.	Anyone near natural disaster.	Aim to finish project early to allow for uncontrollable events that was impact the project completion.	1	3	3	1	2	2
Technical	Code and software bug	Cauing a delay for project	Project success is at risk	Follow gannt chart to leave enough time for debugging.	3	3	9	3	2	6
Project	Lack of material for making the model due to a shortage of the supply or regulations.	Necessary to utilise alternative materials to make the model. Additionally, the PC simulation will need to be redesgined.	Project success is at risk	When choosing materials, check their legality and availablity. Also choose a backup material for unforseeable circumstances.	3	4	12	2	4	8
Project	Members unavailable	Delay in delivarables for the part they cannot take part in.	Project success is at ri	Aim to finish project early to allow for uncontrollable events that was impact the project completion.	5	3	15	5	2	10

Fig. 9 Risk Assessment Table

8 Costing and Funding

In order to deploy an earthquake simulation, detection and analysis system, there are certain costs associated with the necessary equipment. While the software for the system is free, a computer with good performance- costing around £800+ is required to run the software effectively. For the most precise and scientific measurements and calculations, a professional computer costing nearly £1000+ is recommended. In addition to the computer, physical measurements of the power grid require specialized engineering tools such as a laser rangefinder (costing around £300) and a camera (costing around £400-500 or potentially up to £3000 for advanced, earthquake-resistant models). A general tool kit (costing around £100 or up to £200-500 for advanced options) and a GPS device (costing around £300-500) are also necessary for accurate data collection. In a worst-case scenario, the total cost for all required equipment would be approximately £5300.

9 Summary and Conclusion

To summarise and conclude this project proposal, we expect, as a team, that this has solidified the knowledge of the impact of an earthquake and expressed the need to take these precautions to protect electrical systems and attenuate the negative impact of post-earthquake events. Benefits from this proposal should lead to a significant reduction in electrical system damage, less power loss across the grid and the potential to save lives. Ideally, the outcomes of our project proposal lead to the improvement and seismic protection of electrical components within a transmission tower. However, the expected outcome we would be more than happy to accept would be the consideration of further research into what materials are needed to protect the power grid. We also hope that by the completion of this project, we will be able to return to this proposal, having identified key mechanisms that affect the resiliency to earthquakes of electrical components, specifically in transmission towers, hoping to show that our components perform better under experimental but realistic conditions compared to the current components in use.

References

[1] http://www.bristol.ac.uk/engineering/research/earthquakegeo/

[2] https://ourworldindata.org/grapher/earthquake-deaths

[3] https://github.com/NHERI-SimCenter/rWHALE

[4] https://github.com/ahotovec/REDPy

[5] http://assets.pnsn.org/red/

[6] https://github.com/hvasbath/beat

[7] http://www.iitk.ac.in/nicee/wcee/article/WCEE2012_0654.pdf