Real-Time Weather Adaptive Simulation Of Regional Smart Grid For Green Energy Generation

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Abstract: The main aim of this work was to design and develop a real-time simulation system for electrical power distribution in smart grids using renewable energy sources that are to function in different circumstances. The performance of the developed proposed system was evaluated by testing the power generated and power demand using online weather forecasting. Renewable energy was the main power sources with hydro power and diesel as back-up supplies. The system is targeted to generate sufficient energy to meet the power demand even the occurrence of erratic weather. Fuzzy logic is used to enhance and improve the real time and live simulation to make it as realistic as possible, with different sets of rules for each of the influencing parameters, namely, temperature, wind, cloud cover and load as input, and diesel, hydro and battery storage as output control. The results achieved was based on a 5-day forecasting measurement and every 3 hours, while the expected load differs between live and manual measurement. The accuracy and measurement of the overall system was estimated at about 95%. As a future enhancement, a paid subscription for the weather forecasting data to get the full benefit of the options available and allow for 16 days forecasting at intervals of 30 minutes, and secondly to incorporate more accurate calculation for transmission losses and battery storage/charging algorithm.

Index Terms: Battery storage, Erratic weather conditions, Smart grid, Green energy, Fuzzy logic control system

1. INTRODUCTION

Electricity is the easiest and only form of energy which is able be produced and controlled smoothly. Therefore, it is the major form of energy for transmission and distribution (Nag, 2015). Electricity is required to power up virtually all aspects of lives today. The best possible supply of electricity should be dependably given to irrespective of the changing demand. The stability and quality of the power supply and equipment would be damaged by the imbalance between supply and demand, even if it no longer leads to complete unsatisfied demand (Electrical Energy Storage, 2011). The existing power systems, that was established over the past 70 years, feeds electrical strength from giant generators up through transformers to an excessive voltage inter-connected system known as power grids. It is used to transport the electrical energy and then extracted through different types of distribution transformers for the delivery to the customers. The distribution network and the feeding load is very extensive, yet it is totally passive with slight communication and partial controls. Real-time monitoring is not available for either the voltage being accessible to the load or the current being drawn via it (Ekanayake et al., 2012). On the other hand, the Smart Grid is an opportunity towards using new information and communication technologies to revolutionize the electrical power system. It is a mixture of strategies that are aimed to comprehend those goals with the aid of the demanding customers, enhancing the ability of the transmission lines and distribution structure, and providing information and real-time data between the generators, consumers and advanced tiers to utilize renewable resources assets (Ali, 2013).

RESEARCH PROBLEM

Smart grid systems are electrical grids that intelligently respond to the behaviour of electric power consumers and producers (Carpenter & Shaw, 2012). The production of electricity by smart grid generators are based on renewable energy sources, which are uncontrollable and unstable as they mainly rely on the weather variables and weather conditions. The production rate of electricity is therefore not constant. Consumption is also rather varied with time generating peak demand intervals. Therefore, the erratic weather patterns, such as heavy rain or drought for hydroelectric power, cloudy or sunny for solar power, high wind or low wind for wind power and so on, can significantly affect the power generation for smart grids In this study, a simulation is created to be able to show how the smart grid system works under different weather patterns and how it tackles those problems for it to work and function smoothly.

2. AIM AND OBJECTIVES

The aim of this study is to develop a real-time simulation system for electrical power distribution in smart grids using renewable energy sources that are to function in different circumstances. The objectives of this work are:

- To formulate smart power grid calculations for each electrical generation source.
- To design and develop a real-time smart grid simulation system for a targeted region.
- To propose a modified smart grid system using fuzzy logic configuration for improved real-time simulation.

The project would aim to solve the issue faced by the current smart grid simulation systems, which is a lack of accurate measurement of weather patterns for a given design. The simulation would be developed using MATLAB. The main issue that will be tackled in this study will be on erratic weather pattern and how it affects smart grid generation. Assumptions will be based on current and recent designs that will be used for comparison and as reference to be able to make a better and more efficient smart grid simulation model. The goal of the smart grid system in general is be able to have greater efficiency, sustainability in energy usage which requires the best possible alignment of power generation, reliability, consumption of power and storage capabilities. Such alignment usually impacts many factors like power markets, climate conditions and cultural habits (Pochacker, Sobe & Elmenreich, 2013). Proper planning of the simulation model evaluating appropriate settings for different scenarios (e.g., weather, season, load condition, energy storage, etc.) in a smart grid. The model will target a regional area with consumer demands that consists of residential and commercial systems. An algorithm with resilience for preventing the impact of weather events on the smart grid is composed to have a defensive and effective action that adapts to the system and extreme weather variables by using a real time data and utilising an advanced monitoring capability that lies within the smart grid system for increasing the grid flexibility.

DEMAND CALCULATION

The modelling of the smart grid is based on the estimation of a regional area based in Kuala-Lumpur with a population of 60 thousand. The two main energy sources proposed are solar power and wind power, where ideally, they could generate the needed power for the region, with hydropower as a back-up supply. Table 1 shows the arrangement type of both consumers and electrical consumption used for each. From Table 2, the total maximum demand was proposed considering the general hourly based load usage. The average energy usage of a typical residential unit is assumed to be 369KWh/month, i.e. 12.3 KWh/day.

Table 1: Classification of consumers

Type of consumer	Number of units				
Domestic consumer	Double story		Single story		Apartment
	2000		5000		3000
Commercial consumer	Malls	Offices	Restaurant	Hotels	Hospitals
	2	30	20	5	2

Table 2: Total maximum demand

Consumer	Domestic	Commercial
Maximum Demand	122,910KWh	1,087.54KWh
Total Maximum Demand	123,997.57KWh/day	
Annual Total Power	45.25GW	

The system capacity for the smart grid model was set to 5.2MW. The solar power (generated using photovoltaic cells, PV) system generates 60% of the capacity and wind power (via wind turbines) generates 40% of the capacity, as shown in Table 3. Hydro power (via hydroelectric dams) is set as back-up that could generate approximately 100%, when needed.

Table 3: Average supply per day for each source

Power Plant	Capacity (MW)	Capacity Factor
Solar power	3.12	60%
Wind power	2.08	40%
Hydro power	5.2	100%

3.1 Solar PV system

The general formula of solar power (E_{solar}) output of a PV system is given by:

$$E_{solar} = A \times r \times H \times PR \quad (1)$$

where,

A is the Total solar panel Area (m^2),

r is the solar panel yield or efficiency (%),

H is the annual average solar radiation on panels (KWh/m^2).

PR is the performance ratio of the PV system.

For Malaysia, H is estimated to be $16.26\ ^{MJ}/_{m^2}$. Converting from joule to Wh, gives:

$$H = 16.26\ ^{MJ}/_{m^2} \times \frac{1}{3600} = 4.5167\ KWh/m^2 \quad (2)$$

The average PR with an efficient inverter is assumed to be 0.75. For maximum yield, the solar panel yield, r was assumed to be 20%, as current commercialized standard crystalline silicon modules have efficiencies of just that.

The desired solar annual energy production, from the average of 8 hours' daylight received, is given to be:

$$\text{Annual } E_{solar} = 3.12\text{MW} \times 365 \times 8 = 9110 \text{ MWh} \quad (3)$$

Thus, the area of solar panel coverage could be calculated as:

$$A = \frac{9110\times10^6}{0.2\times1648583\times0.75} = 36839.7 \approx 36840\ m^2 \quad (4)$$

The number of solar panels assumed to be $370W_p$ panels which needed to cover $36840m^2$ for the system and could be calculated by finding the DC power needed to obtain the 3.12MW AC power desired. Given the efficiency of DC to AC conversion from the PV module is 80%,

$$\text{DC power needed} = \frac{3.12MW}{0.8} = 3.9\text{ MW} \quad (5)$$

$$\text{Number of panels required} = \frac{3.9MW}{370W_p} = 10540\ panels \quad (6)$$

3.2 Wind turbine system

The general formula of wind power output of a wind system is given by:

$$E_{wind} = \frac{1}{2} \times \rho \times A \times Cp \times V^3 \quad (7)$$

The meaning of the notations used in Eq. (8) are given in Table 4, along with the assumed corresponding values. According to (Belhamadia, Mansor and Younis, 2014), wind speed velocity could reach a maximum of 3.97 m/s and drops to a minimum of 2.17 m/s with air density evaluated to be $1.17\ Kg/m^3$ as an average temperature in Malaysia. The calculation of the swept area of the turbine is determined from the length of the turbine blades using the equation for the area of a circle.

Table 4: Assumptions made for wind turbine system

Parameter	Assumed Value
Air density (ρ)	$1.17\ Kg/m^3$
Swept area (A)	$8495m^2$
Power coefficient (Cp)	0.4
Wind speed (V)	3.97 m/s
Blade length (l)	$52m$

The power generated per turbine could be calculated using Eq. (7) with the assumed values in Table 4, as shown below:

$$E_{wind} = 124.38KW\ per\ turbine \quad (8)$$

$$\text{Total turbines} = \frac{2.08MW}{124.38KW} = 16.7 \approx 17\ turbines \quad (9)$$

3.3 Hydro power system

The general formula for calculating the theoretical power output of a hydroelectric system was given as:

$$E_{hydro} = \rho \times i \times HQ \quad (10)$$

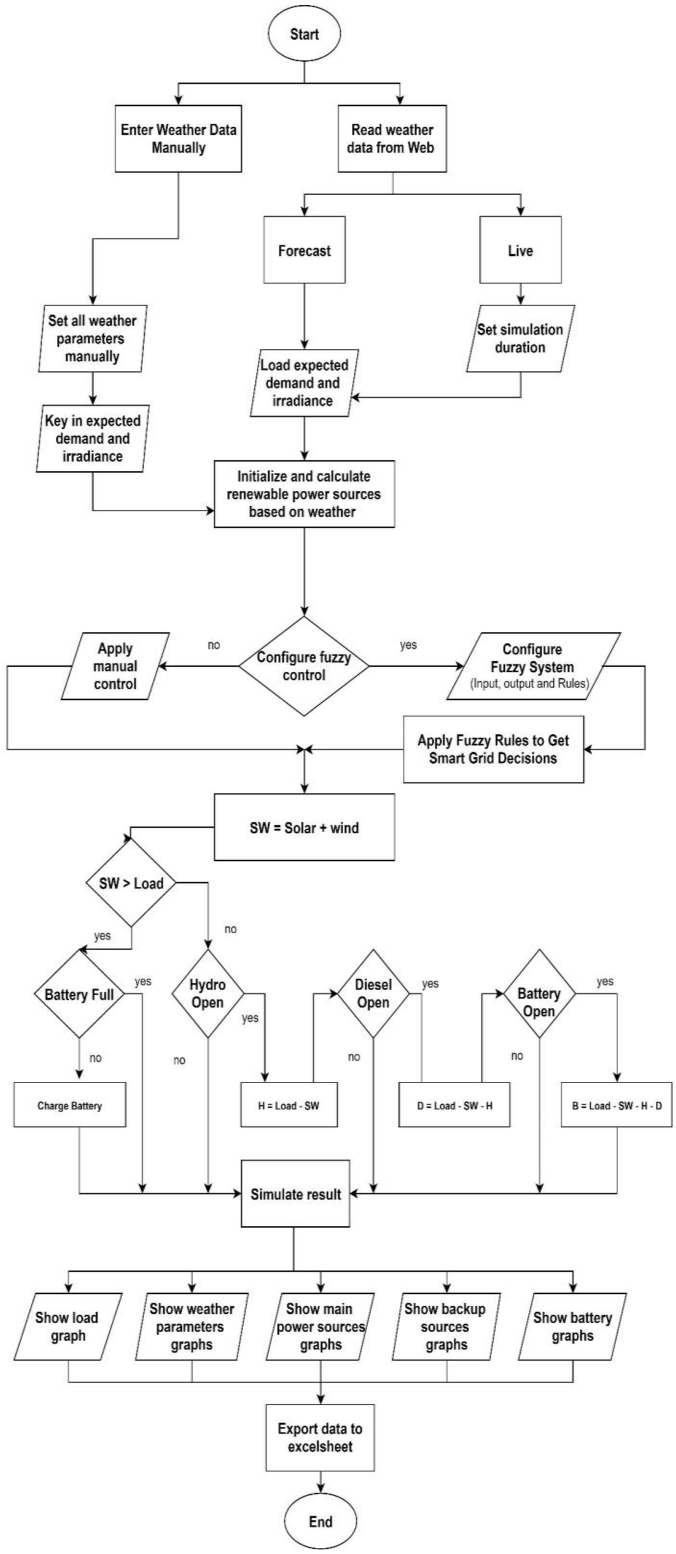
Considering the hydroelectric system is used as backup power generator in case of solar or wind power cannot meet the desired power for the selected region. Therefore, the desired power that needs to be generated by the system is 5.2 MW. The total system capacity of 5.2 MW is more than enough to fulfil the maximum demand of the customers. However, having to generate more than needed would be economically and environmentally unfeasible. Therefore, calculations were to be made to balance the system generation of electricity to minimize wastage of energy and still provide enough energy to fulfil customers' demand.

3.4 Block diagram

Figure 1 shows the block diagram of the system, with all the main parts including the communication system between the online weather forecasting and the configuration of the power load parameters. The system works based on the data collected from the universal weather data provider service, where is it responsible to collect current weather data such as temperature, cloud cover, wind speed which will be shown in the graphs as an output and the daily solar irradiance. The expected hourly power load module allows the user to enter the expected load manually at the beginning of the simulation based on the calculated daily demand calculation in chapter 3 then the demand was broken down into hours based on the consumer usage per hour. Another option that the load can be changed while running the simulation process to simulate the real time live case and run it per minute or hour. In the power source simulator module, the system calculates the power generated using different sources based on the equations and calculation done in section A-C and it is connected to weather forecasting module since some of the parameters are needed from the universal weather service. The power sources include the renewable sources (solar, wind and hydro), diesel and backup battery supply. The fuzzy logic unit in the controlling and monitoring unit is programmed with fuzzy logic configuration to be applied to control the smart grid based on the weather status in order to utilize the cost of power to the minimum and reduce the probability of loss to the maximum. Another advantage is to make the system more automatic and smart so that it can be able to make decisions on its own without the need of human interface. The graphical user interface (GUI) of the system shows all the related data including the system status, control and monitoring alongside all the parameters. All inputs and outputs power are presented in the smart grid simulator to reflect the existing state of the smart grid.

3.1 Working principle

The system for the real time weather adaptive smart grid is considered a visualization and monitoring system that can be able to generate enough power for the consumers even under erratic weather circumstances. The whole working principle as shown in Figure 2 shows how the system mostly depends on the universal weather provider service for the weather data since the system is weather based. To simulate the system there are two options to start the process, either manual data entry which allows the user to key in all the weather variables, parameters, load demand and irradiance or the second option to read all the data from the online weather provider service which provides the actual temperature, wind speed and cloudiness rate. After reading the weather data online there are another two options to initialize the system either to have under forecast parameters where it will take the data for the next 5 days or to have a real time measurement where it will show a live minute by minute simulation. After setting all the weather parameters, initializing and calculation the renewable power sources, diesel and battery systems are set based on the weather data taken. This will allow the power generators to generate power according to the current or forecasted weather and have it as a realistic measurement and will show actual results based on the given calculations. If the generated power is not meeting the power demand, then there are two options to generate the extra power. The first option is to configure the controls of the back-up power manually where it will be possible to switch on/off the hydro, diesel and battery systems manually if needed. The second option which is the fuzzy logic control which will allow the system to decide what needs to be done automatically and make decisions on its own without the need of human interface. Finally, after initializing and configuring all the necessary rules and parameters then simulating the system and show all the parameters (power demand vs generated power, temperature, cloud, wind speed, solar power, wind power, hydro power, diesel and battery) in graphs the simulated results could be exported to an excel sheet for testing and safe record. The real-time weather adaptive smart grid system is designed to be able to handle different types of weather variable and to generate the needed power for the consumers (domestic and commercial) under multiple circumstances. As explained in the system flowchart the design and programming were done in MATLAB 2018. There are three different types of simulation configuration (5 days forecast, manual and live simulation) and can be measured either by using fuzzy logic configuration which makes the system under automatic setting and manual simulation to control the system manually.



SIMULATION RESULTS

The first result shown in Figure 3 is simulated under the simulation option which is to simulate a forecast data for the next 5 days every 3 hours. In this case solar and wind are hugely affected since wind speed and irradiance gradually changes and at night solar will mostly generate very low power, which will automatically turn on the hydro power switch to compensate for the remaining demand. 7% transmission losses occur and therefore diesel had to start generating some of the power and the extra power in stored in battery, which results in battery charging. The second simulation result demonstrates the manual simulation where all the weather and irradiance parameters are done manually without using any online source as shown in figure 4. This option allows the user to key in the load, temperature, wind speed, irradiance and clouds for the next 24 hours. The final simulation illustrates the live results which was done for a duration of 1 hour to show how the system reads the data online and simulates simultaneously. The initial load and irradiance are set manually however all the weather parameters are taken live. The change in load demand and load generated is due the minute by minute data entry done to keep the system as accurate as possible.

CONCLUSIONS

In conclusion, the goal and objectives have been achieved by designing real-time weather based smart grid system. The system consists of two main generating parameters which are solar and wind powers, a back-up renewable source which is hydro power and another two sub-backup sources which are, battery storage and diesel power, as a last option if there is shortfall in the power generation using the renewable sources.

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