OPTIMAL ENERGY MANAGEMENT SYSTEM FOR A NET ZERO BUILDING USING MULTI-AGENT SYSTEMS APPROACH

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Abstract

Buildings have a significant impact on energy usage and the environment. Much of the research in architectural sustainability has centered on economically advanced countries because they consume the most energy and have the most resources. However, sustainable architecture is important in developing countries, where the energy consumption of the building sector is increasing significantly. The aims of this study are investigating using the hybrid system, which formed by interconnecting two source of renewable energy as solar and wind along with city grid for compensation purposes wherever it is required. In this study, after literature review, we consider the case study and its assumptions, System description and its characteristics following by discussion of renewable energy sources in more details. Furthermore, the optimization and prediction issues and the data uncertainty in this field have considered. Then, the net logo programming language is utilized for simulation of the system.

Key words: Net zero energy building, Solar, Wind, Simulation, Net logo programming.

Introduction

During the last ten years, the world has awakened to the fact that fossil fuels are causing tremendous damage to the earth. More importantly, these non-renewable energy resources are quickly dwindling and will no longer be available in the near future due to rapid exploitation. Environmental phenomenon, such as global warming and depletion of the ozone layer attributed to emissions from massive fuel combustion are slowly but surely causing widespread problems to every living thing on earth. With uncertainty over the availability of fossil fuels into the future, rising demand for fossil fuels, rising concerns over energy security and the potential that greenhouse gases may be negatively affecting the world's climate. Hence, it is essential to find ways to reduce load, increase efficiency, and utilize renewable fuel resources in facilities of all types. Renewable energy is one very effective solution available today [1]. Solar cells represent the fundamental power conversion unit of a photovoltaic system [2]. Generally, the Solar Cell performance varies with the weather. Especially in the winter in the thermal power plant areas the presence of fog, dust affect the Solar cell performance. So, the solar tracking system is used for increasing the efficiency of the overall system.

In particular, meeting the energy demand in a hybrid system for net zero building is challenging task that required taking into account many different elements. The main concern is that the renewable sources of energy alone cannot meet the required electricity demand and continuously. In addition, the availability of the generated power depends on the weather and climatic condition. The building industry can significantly reduce energy use by incorporating passive and active energy strategies into the design, construction, and operation of new buildings and existing buildings.

In other hand in decentralized energy system, a number of smaller power plants produce the electricity. In the other words, it could state that the energy is produced at the same place. The decentralized energy system is more consumers interactive and it could more properly meet the requirements of this study. In this study, the aim is investigating using the hybrid system, which formed by interconnecting two source of renewable energy as solar (PV arrays) and wind (turbine) along with city grid for compensation purposes wherever it is required. It is believe it is the best approach to meeting the energy demand of the building that being cost effective and reliable. The study focuses on agent based modeling technique in order to optimize the power distribution in a net zero building. It is a building that is efficient enough to produces as much energy as it consumes. For demonstration purposes of the applied method, some assumptions are made for testing the robustness of the model. The major scope of this study is to investigate the agent based modeling techniques to optimize the distribution of generated power from two source of renewable energy (solar and wind) along with using city power for compensation purposes. The region of the model under the study considered El Paso and the time of the model execution is assumed to be during the summer. By optimizing the power distribution in a net zero energy building, saving energy bills, improving the health and wellbeing to maintaining the competitive advantage are obtained from multiply ways.

Methodology

In this project in order to demonstrate the stated algorithm, a simple practical scenario with the following assumptions has formulated and simulated in Net logo; there is a building that its required electricity needs to be provided through renewable energies, solar and wind in here. The building has equipped with a battery with an indicator. When the indicator shows that the stored electrical energy is lower than a certain required amount, depends on the time of the day, three source of energy as solar, wind and city power would be utilized.

By considering the weather in El Paso the twenty fours of a day has divided into three periods.

1. From 7AM to 5PM, the solar energy is used. From 5AM to 8PM, the power city is in used. From 8PM to 7AM, the wind energy is used.

Moreover, the assigned agents are as below:

1. Building agent (represent the consumption electricity), Decision agent which act according to the time of the day and the state of indicator, Battery agent, Solar, wind and city power agents, Environment agent (day& night)

Main techniques for forecasting the output power of solar and wind systems are as bellows; [37].

- Time-series analysis, Regression, Neural Network, Hybrid Method: neuro-fuzzy, wavelet-NN, Others

For this case study, the following information would help to effectively determine and define the assumptions of the model.

Irradiance data will be from the location of El Paso, Texas, assuming its summer for optimal sun time and intensity per day [45]. This information already takes into account the variation due to clear skies and cloud presence.

The simplified DNI behavior for this case will be as Eq (3-7)[46]:

$$DNI(h) = \begin{cases} 0, & 0 > h > 6 \\ N(400,190), & 6 > h > 9 \\ N(670,255), & 9 > h > 11 \\ N(738,236), & 11 > h > 14 \\ N(661,290), & 14 > h > 16 \\ N(422,291), & 16 > h > 19 \\ 0, & 19 > h > 24 \end{cases} \qquad (3\text{-}1)$$

The DNI behavior is shown in the graph below [46], in which the maximum and minimum DNI are graphed. The variation of the behavior comes from the standard deviation of each range.

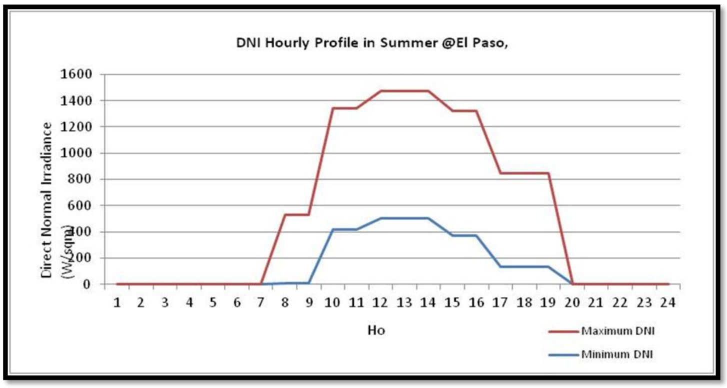

Figure 3.4: DNI Hourly Profile in summer

Therefore during the time period of 7am to 5 pm the solar panel is the most suitable source. In addition given that El Paso is a low wind speed area, low speed wind turbines are considered for this case study. This means that the wind turbines will generate power when the wind speed is between 3 mph and 12 mph. with considering the wind speed average based on the past two summers, in El Paso, Texas [44], the time period of 8pm to 7am can be best time for using wind power.

Simulation, Results and Analysis

In this study, the multi agent base modeling methodology with the focused on decision making(choosing appropriate source of energy according to time of the day), is utilized for the purposes of optimization of the energy in the building. This simulation modeling technique contributes to optimize the distribution of the electricity generated. In addition, Net Logo as a simple and comprehensive simulation tool, has used for analyses and validation of the proposed approach.

Agent based modeling is a new approach for the simulation of various systems. Applications of agent-based modeling are used in wide fields, for instance the stock market [47], consumer purchasing behavior [48], Health Care [49] and many other applications.

An agent can be defined as independent component's behavior that can range from primitive reactive decision rules to complex adaptive artificial intelligence (AI) [51].

In other hand, Casti [52] argues that agents should contain both base-level rules for behavior as well as a higher-level set of "rules to change the rules." The base-level rules provide responses to the environment while the "rules to change the rules" provide adaptation. An agent can act autonomously, which means respond to different situation without any external direction. Make decision independently, which required agent to be more active rather than passive.

Agent behavior describe by simple rules. They can learn and adopt themselves to improve their environment. The fundamental feature character of an agent, which is self-organize, and the interaction between agents could affect their behavior.

Two primary issues of modeling agent interactions are specifying that who can communicate with others, and the mechanisms of the dynamics of the interactions. Both aspects must be addressed in developing agent-based models.

Agent-based systems are decentralized systems. There is no central authority that either pushes out globally available information to all agents or controls their behavior in effort of optimize system performance. Agents interact with other agents, but not all agents interact directly with all other agents at all times, just as in real-world systems. Agents typically interact with a subset of other agents, termed the agent's neighbors. Local information is obtained from interactions with an agent's neighbors (not any agent or all agents) and from its localized environment (not from any part of the entire environment).

Agent-based modeling can be used general, all-purpose software or programming languages, or it can be applied specially for designed software and toolkits that address the special requirements of agent modeling spreadsheets, such as Microsoft Excel, in many ways offer the simplest approach to modeling. Development model is simple with spreadsheets than with many of the other tools, but the resulting models generally allow limited agent diversity, restrict agent behaviors, and have poor scalability.

General computational mathematics systems such as MATLAB and Mathematica, which many people may be already familiar with, can also be used quite successfully; however, these systems provide no specific capabilities for modeling agents.

General programming languages such as Python, Java, and C++, and C also can be used, but development from scratch can be prohibitively expensive, as there are no dedicated libraries or modules that focus on agent-based modeling [53].

Net Logo is a multi-agent programming language and modeling environment for simulating complex phenomena [56]. Net Logo is a free ABMS environment developed at Northwestern University's Center for Connected Learning and Computer-Based Modeling [56]. The Net Logo language uses a modified version of the Logo programming language [56].

Net Logo is written in Java, version 1.4 and enables the user to create its own model and explore the behavior of agents under different conditions. In addition, the language includes commands that let you read or write any kind of text file.

Table 4.2: Comparing Agent Based Modeling [57]

Platform of ABM	Ascap	Mason	Repast	Net Logo	SWARM
Quantity of user	Low	Growing	High	High	Low
Language	Java	Java	Java Python	Net Logo	Java
Speed and Programming	Moderate	Faster	Fast	Moderate	Moderate
Learning facility	Moderate	Moderate	Moderate	Moderate	Moderate
Documentation	Good	Little	Little	Large	Good

The main concepts of the software design are discussed. In the initial stage of the modeling simulation, the agents should be defined and be assigned properly. For the purposes of this study, the required agents define as:

- Battery, Sun, Wind,Electric-city,Building, Environment Day& Night

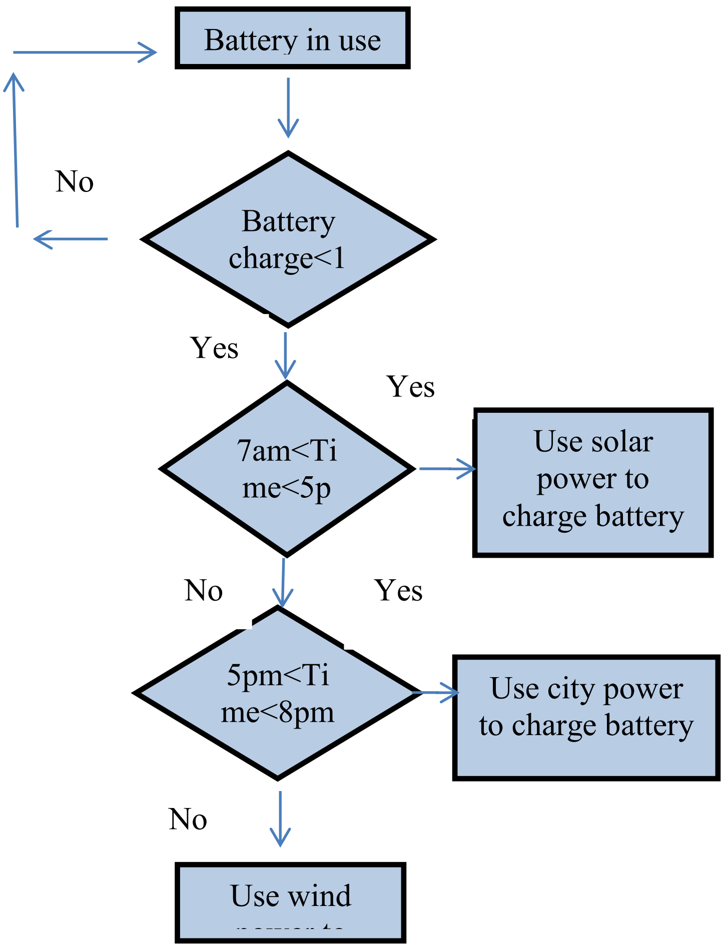

Figure 4.4: System Operation Flowchart.

The energy will be captured by solar panel and wind turbine. Therefore the agents for this simulation are solar panels and wind turbines, while the City Power Supply used as a backup. The aim is firstly use the renewable energy and use the City Power Supply as the last option. The time is during summer and its unit is a tick counting as a minute.

In software section of the model we have “counter”, “time”, “reporter” to report whether it is AM or PM, “bf!size” is to report amount of battery charge and “energy use” is to show which source is under the used. As it can be seen for simulation of this modeling, all the agents are required to act accordingly on specific times. Therefore, pre-processing instructions will be essentials.

The duration of this simulation is 24 hours. If the counter value gets less than 12 hours then it is AM otherwise the displayer shows PM. In other hand whenever the counter amount reach to 24, it would reset again to zero. For the battery , if it is charged bigger than 90% then the monitor shows “battery full true” and if the charge of battery gets below 90% then the message “battery full false” would be displayed.

Conclusions and Recommendations for Future Work

In this work, an approach to design and optimize of power generation system in a low energy building has been proposed. The system utilize two renewable source of energy, wind and solar and the city power grid is available in emergency cases when the two other source will not be available. Beside by providing numerous data along with mathematical formula, the amount of energy generated tried to be predicted.

In this study, in order to address the system requirements the use of agent-based simulation is explore to model the aspect of energy flow in the distributed building system. The uncertainty in the energy system is the most challenging part of the simulation. Therefore, an optimal decision strategy should implement in the system to overcome this issue. Later on by comparison between different available toolkits the Net Logo software has chosen to execute the model.

Finally, the required codes have been written for a simple scenario in order to illustrate the use of Net logo in this project.

This study contributed to mitigate the problem of optimization of renewable energy distribution by developing a hybrid intelligent energy distribution system in a net zero building by utilizing of agent based modeling system. The following were the major contribution to this study.

- The application of the agent based modeling technique; work well with the energy management system approach in this study.
- Optimization of energy distribution enhances the overall performance of the net zero building.

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Appendix I

NETLOGO CODES

```
breed[battery]
breed[sun]
breed[wind]
breed[Electric-City]
breed[Building]
breed[Environment]
globals[day&night

   counter
  time
  reporter
  b-f
  size!
  rvb
  Energy use
  s1
  s2
  s3
  charging
  bch
  patch-ch
  ]

turtles-own [total-battery]


to setup
  clear-all
  set  day&night true
  set counter 0
 set patch-ch 0
  patcheset
  change-patches
  setup-battery
  setup-sun
  setup-wind
  setup-Electric-City
end


to go
  set time counter
  set counter counter + Speed
  ifelse counter <  12 [set reporter "AM" set day&night
true  ][set reporter "PM" set day&night false]
  if counter  >= 24 [set counter 0]

  change-patches

 ask battery [ ifelse total-battery  > 90 [set b-f "true"][set
b-f "false"]]
 check-battery

 checking
 ;;go-charging

end



to patcheset


  ask patches [set pcolor white]

    ask patches with [ pxcor > 7   ]
    [ set pcolor 133 ]

    ask patches with [ pxcor > 24   ]
    [ set pcolor white ]


     ask patches with [ pycor > 24   ]
    [ set pcolor white ]



end



to change-patches
  if day&night = true [

  ;;right
   ask patch 20 20 [ set pcolor white]

   ask patch 20 15 [ set pcolor white]

   ask patch 20 10 [ set pcolor white]

   ask patch 20 5 [ set pcolor white]



   ;;left
   ask patch 12 20 [ set pcolor white]

   ask patch 12 15 [ set pcolor white]

   ask patch 12 10 [ set pcolor white]

   ask patch 12 5  [ set pcolor white]

   ;;center
   ask patch 16 20 [ set pcolor white]

   ask patch 16 15 [ set pcolor white]

   ask patch 16 10 [ set pcolor white]

   ask patch 16 5  [ set pcolor white]]
```

```
 if day&night = false [

 ;; ask patches [set pcolor black]

  ;; ask patches with [ pxcor > 7   ]
 ;;  [ set pcolor 133 ]

;;   ask patches with [ pxcor > 24   ]
 ;;  [ set pcolor black ]

  ;;  ask patches with [ pycor > 24   ]
;;   [ set pcolor black ]
 ;;right
  ask patch 20 20 [ set pcolor yellow]

  ask patch 20 15 [ set pcolor yellow]

  ask patch 20 10 [ set pcolor yellow]

  ask patch 20 5 [ set pcolor yellow]

  ;;left
  ask patch 12 20 [ set pcolor yellow]

  ask patch 12 15 [ set pcolor yellow]

  ask patch 12 10 [ set pcolor yellow]

  ask patch 12 5  [ set pcolor yellow]

  ;;center
  ask patch 16 20 [ set pcolor yellow]

  ask patch 16 15 [ set pcolor yellow]

  ask patch 16 10 [ set pcolor yellow]

  ask patch 16 5  [ set pcolor yellow]]

end

to setup-battery

 create-battery 1
 ask battery [ setxy 4 3

   set shape "target"
   set color lime
   set size 4

   ]
  ask battery[set total-battery total-battery + Battery-
power
 ;; set label total-battery]
  ]
end

to check-battery

  ask battery[
    ifelse total-battery > 0 [set use "battery energy"
    set total-battery total-battery - 0.001
    ;;set label total-battery
    set rvb total-battery
    set color color + 1
    ]

    [set rvb 0]
    if total-battery < 0 [level2    ]
  ]
end

to level2

  if counter > 7  [ set s1 "true" set s2  "false" set s3
"false"

     ]
  if counter > 17 [set s1 "false" set s2  "true" set s3
"false" ]
  if counter > 20 [set s1 "false" set s2  "false" set s3
"true"

     ]
end

to checking

  if s1 = "true" and s2 = "false" and s3 = "false"[ask
battery[ if total-battery < 0  [  go-charging] ]
    set use "solar energy"
    ask sun [set color color + 1  ]
    ask sun[if any? Building-here [go-reduce] ]
    ]

  if s1 = "false" and s2 = "true" and s3 = "false"[  set bch
"false"
    set use "Electric City"
    ask Electric-City [set color color + 1  ]
    ask Electric-City[if any? Building-here [go-reduce2]
]
    ]

  if s1 = "false" and s2 = "false" and s3 = "true"[ set bch
"false"
    set use "wind energy"
```

```
    ask wind [set color color + 1  ]
    ask wind[if any? Building-here [go-reduce3] ]
    ]


end


to setup-sun



  create-sun 1
  ask sun [ setxy 4 9

    set shape "target"
    set color orange
    set size 4

    ]


end





to setup-wind



  create-wind 1
  ask wind [ setxy 4 15

    set shape "target"
    set color blue
    set size 4

    ]


end




to setup-Electric-City


  create-Electric-City 1

  ask Electric-City
 [ setxy 4 21

    set shape "target"
    set color yellow
    set size 4

    ]
```

```
end
to go-charging
  set bch "true"
  ask battery[set total-battery total-battery + 100]
  set patch-ch patch-ch + 1
  ask patch patch-ch 30  [ set pcolor lime]


end
to go-reduce
   set breed Building
  set shape "target"
  set color red
  set size 0.5
  ask sun[
  ifelse [pcolor] of patch-ahead 1 != white
      [ lt random-float 360 ]
      [ fd 0.00001 ]    ]

  ask Electric-City[
  ifelse [pcolor] of patch-ahead 1 != white
      [ lt random-float 360 ]
      [ fd 0.00001 ]    ]

  ask Building[
  ifelse [pcolor] of patch-ahead 1 != white
      [ lt random-float 360 ]
      [ fd 0.00001 ]    ]
end

to go-reduce2
   set breed wind
  set shape "target"
  set color red
  set size 0.5
  ask sun[
  ifelse [pcolor] of patch-ahead 1 != red
      [ lt random-float 360 ]
      [ fd 0.00001 ]    ]

  ask Electric-City[
  ifelse [pcolor] of patch-ahead 1 != red
      [ lt random-float 360 ]
      [ fd 0.00001 ]    ]

  ask Building[
  ifelse [pcolor] of patch-ahead 1 != red      [ lt random-
float 360 ]
      [ fd 0.00001 ]    ]

  end

to go-reduce3
   set breed sun
  set shape "target"
  set color red
  set size 0.5
  ask sun[
  ifelse [pcolor] of patch-ahead 1 != orange
```

```
    [ lt random-float 360 ]
    [ fd 0.00001 ]    ]

  ask Electric-City[
  ifelse [pcolor] of patch-ahead 1 != orange
    [ lt random-float 360 ]
    [ fd 0.00001 ]    ]

  ask Building[
  ifelse [pcolor] of patch-ahead 1 != orange
```

014) 2421–2431.

```
    [ lt random-float 360 ]
    [ fd 0.00001 ]    ]

End
```