International Journal of Engineering Research and General Science Volume 7, Issue 3, May-June, 2019
ISSN 2091-2730

Case Study: Kalangala Infrastructure Services

Ekuru Ebyau Edward[1], Andima Moses[2] Geofrey Bakkabulindi[3]
Prof. Latin Okidi[4]
[1,2] Makerere University, College of Engineering Design Art and Technology,

Department of Electrical and Computer Engineering, Makekerere Hill, Kampala, Uganda,

ekuru.ebyau@gmail.com, Corresponding Author.

[3]College of Engineering Design Art and Technology, Makerere University,

Department of Mechanical Engineering, Makekerere Hill, Kampala, Uganda,

geofrey.bakka@gmail.com

[4]Makerere University, College of Engineering Design Art and Technology,

Department of Mechanical Engineering, Makekerere Hill, Kampala, Uganda,

englating@gmail.com

Abstract- In this study, the subject of Economic Dispatch (ED) for a hybrid power network comprising of renewable energy (662 kWp Solar PV), non-renewable diesel generators (500, 320, 200 KVA) and energy storage system (655 kWh for 10 hour) is considered. The study which sought to determine an economic operation of the hybrid system by optimizing generation, energy storage and discharge. The study also considered silent costs such as: starting, shut, ramping and storage costs for all the associated units. This ED was formulated as an optimization problem solved using Mixed Linear Integer Programing techniques (MILP). The results indicated a total daily cost of USD. 3780.9 for a total load of 7.94 MW with poor PV generation up take. The study proposed a load increase and profiles which resulted into a total generation of 10.2 MW with a cost of USD 2,065.4 with over 95% PV utilisation. Overall, the results indicate that renewable energy dispatch in a hybrid mode does not necessary present the most economical dispatch under all conditions.

Key words: Economic Dispatch, Hybrid Grids Optimisation, Storage Energy Optimisation.

1 INTRODUCTION.

Hybrid power networks comprise of electricity generation sources with varying technologies, integrated into one network to serve the load. [1][2]. Hybrid networks have also promoted the shift from traditional central generation sources to distributed multigenerational network. The drive for has been the attractive cost benefits of mainly emerging renewable energy sources and global trends in capping green-house emissions. [3]. The cost benefits associated with each generation in a pool has to be economically dispatched.

The subject of economic dispatch of electricity power systems has been considered by [4], [5], [6] and [7]. In these studies, the optimisation of the energy storage system was not considered and as well as intermittent renewable energy or the combination of both.

Techno-economic assesment of PV installations only was done by [8] and [9] recommended that hybrid was the best choice as compared to diesel only. [10] included wind variability in the economic dispatch, [11] makes a consideration of the environmental factors for economic dispatch. In the above foregoing the rationale for intergrating renewable energy has had the general notion of reduced cost however [12] showed an inrease in the costs of thermal generation providing back up.

The study aims at developing an economic dispatch model for the hybrid and testing it under the curent condition. The network and generation parameters are simulated using MATPOWER[13] format and solved using MOST tool. The varaitions of costs for each of the generators is presented under the differerent scenarios of the study.

2 NOMENCLATURE

The following terms and variables are thus defined as below:

C_p^{ti}	Cost function for active injection for unit *i* at time *t*.
$C_p{}^{it}$,	Cost of active power from generators (Diesel and Solar PV).
C_ps^{it},	Initial stored energy in the battery storage system,
$C_{p+}{}^{it}$, $C_{p-}{}^{it}$	Charging and discharging (energy generation from the storage system) costs.
$C_\partial{}^i$	Symmetrical Ramping costs on the different dispatches for unit i during adjacent periods.
$C_v{}^{it}, C_w{}^{it}$	Start up and shut down costs
p^{ti}, q^{ti}	Active and Reactive energy for unit i
$\vartheta, v, p^{ti}q^{ti}$	Voltage angles, magnitudes, Active and reactive power injections respectively in the post contingency mode.
s_+^{ti}, s_-^{ti}	Computed upper/lower bound on the energy storage unit I at the end of period t.
s_0^i	Initial charge stored.
$P_{min}^{ti}, P_{max}^{ti}$	Limits of active power injection
p_{sc}^{ti}, p_{sd}^{ti}	Active power generated stored and dissipated by the storage system respectively.
S_{max}^t, S_{min}^t	Maximum and minimum Stored energy in MWh
$S_{max}^{io}, S_{min}^{oi}$	Minimum and maximum initial energy storage bounds
$S_{max}^{nti}, S_{min}^{nti}$	Lower and upper bounds on storage energy targets respectively.
$v^{ti}, w^{ti}u^{ti}$	Binary start up, shut down and Unit commitment states for unit i in the period t, ie 1 for shutdown/start up during a period otherwise 0.

2.1 Economic Dispatch model

The economic dispatch model was formulated as an optimisation problem.

$min\, f(x)$ [2-1] $-$

s.t $A(x) = 0$ [2-2]

$B(x) \geq 0$ [2-3]

$D(x) \leq 0$ [2-4]

Where f represents the total generation cost (including the start-up and shutdown costs),

A represents equality while B represents inequality variables.

x represents state variables such as phase angle ϑ, Voltage magnitudes,Venergy generation p, reactive energy generation q, energy stored, p_{sc}, energy discharge, p_{sd} and Initial stored energy, s_0.
Therefore, x was formulated as follows:

$f(x) = f(p, +p, -p) + f(s_0, p_{sc}, p_{dc})$ [2-5]

2.2 Active energy dispatch and redispatch costs

$f(p, +p, -p) = \sum_{i,t=1,0}^{i,t=T} C_p{}^{it} * p^{it} + C_p s^{it} * ps^{it} + C_{p+}{}^{it} * (p+^{it}) + C_{p-}{}^{it} * (p-^{it}) + f_\partial(p) + f_{uc}(u, v, w)$ [2-6]

2.3 Start up and shutdown costs.

$f_{uc} = \sum_{t \in T}\left(C_{p0}^{ti} * u^{ti} + C_v^{ti} * v^{ti} + C_w^{ti} * w^{ti}\right)$ [2-7]

2.4 Ramping costs:

$f_\partial(p) = c_\partial^i(p^{ti} - p^{(t-1)i})$ [2-8]

2.5 Storage energy associated costs

$\boldsymbol{f}(s_0, p_{sc}, p_{dc})$ [2-9]

The constraints are given as power flow is given as:

2.5.1 Power balance

$g^{itk}(\theta^{ijt}, V^{ijt}, P^{ijt}, q^{ijt}) = 0$ [2-10]

2.5.2 Transmission limits

$h^{itk}(\theta^{ijt}, V^{ijt}, P^{ijt}, q^{ijt}) \leq 0$ [2-11]

2.5.3 Storage dispatch constraints

$p^{ti} = p_{sc}^{it} + p_{sd}^{it}$ [2-12]

$p_{sc}^{it} \leq 0$ [2-13]

$p_{sd}^{it} \geq 0$ [2-14]

$S_-^{ti} \geq S_{min}^{ti}$ [2-15]

$S_+^{ti} \leq S_{max}^{ti}$ [2-16]

3 CASE STUDY

The study focused on KIS hybrid power plant under the prevailing loading conditions and also under the improved hypothetical load profile. The effects of increased load was studied together with other costs applicable shown in Table 1.

Table 1: Showing the Generator associated costs

Gen	Start	Stop	Ramp	Start/Sop time (s)
1	600	300	500	600
2	500	200	400	400
3	300	100	300	300

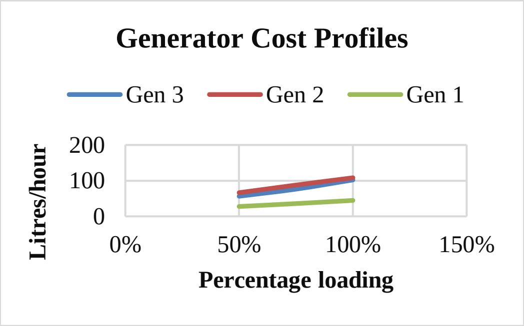

Figure 1: Showing the cost functions of the various generators.

4 RESULTS

The model developed was tested under two scenarios of the low load scenario and the scaled up load scenario. The model's planning period was started at mid night.

4.1 Low load condition

Form the generation and storage profiles in , it was clear that the generator 1 and 3 were online supporting the load. Gradual increment in the PV generation increased while the load decreased as shown in as shown in **Error! Reference source not found.** and **Error! Reference source not found.**. The small load changes were born by the ESS and the costs associated are given in **Error! Reference source not found.**. The total generation for the planning period was 10.15 MW for a total cost of USD. 3,968.

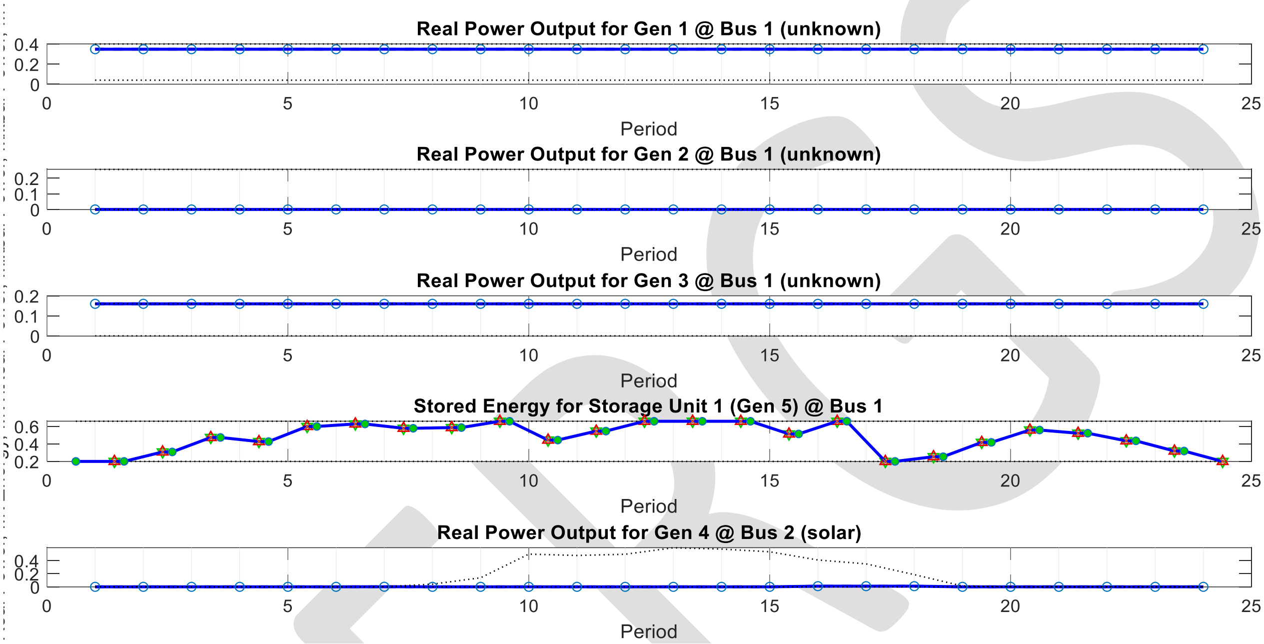

Figure 3: Generation profiles for each planning interval.

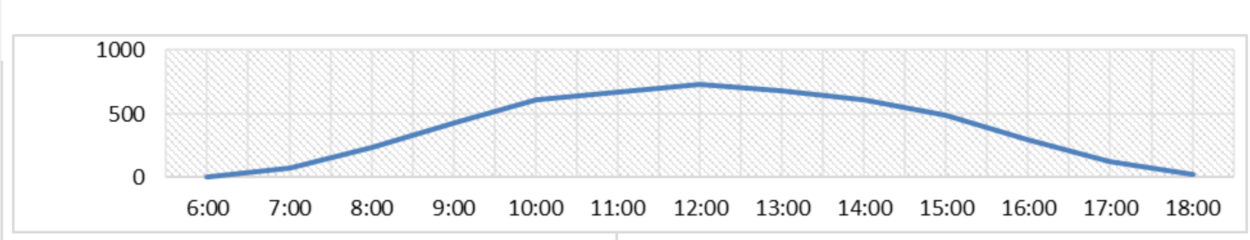

Figure 2: Showing the average PV output in W/m2 during the period of the day

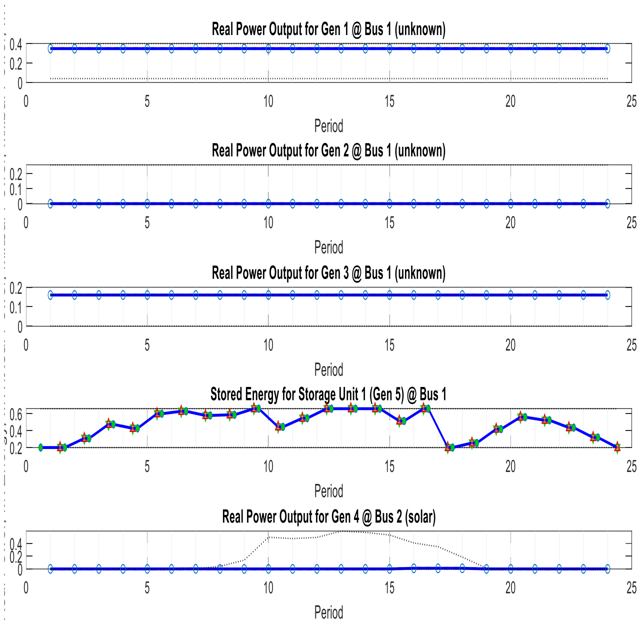

Figure 5: Generation profiles for each planning interval.

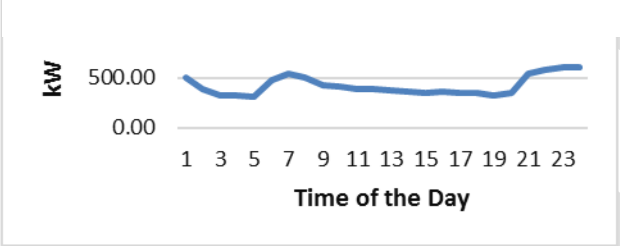

Figure 7: Showing the average daily load profile in kW

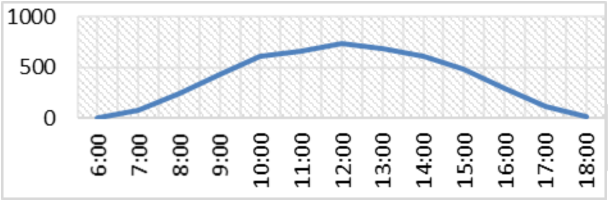

Figure 6: Showing the average PV output in W/m2 during the period of the day

4.2 Ramped Load Condition

Under these conditions, the load was scaled upwards and the load profile shifted as shown in Figure 7. All the generators were online serving the load. The total cost of generation. USD. 5,892.9 for a total load of 21.61861 MW as compared to USD. 3,968.1 for 10.15 MW derived from the first case. The utilisation of the PV system was better for the new load profile.

5 DISCUSSION

The optimization model was developed and tested by means of a case study considered two scenarios of low load (base case scenario) and the second scenario where the load was scaled upwards.

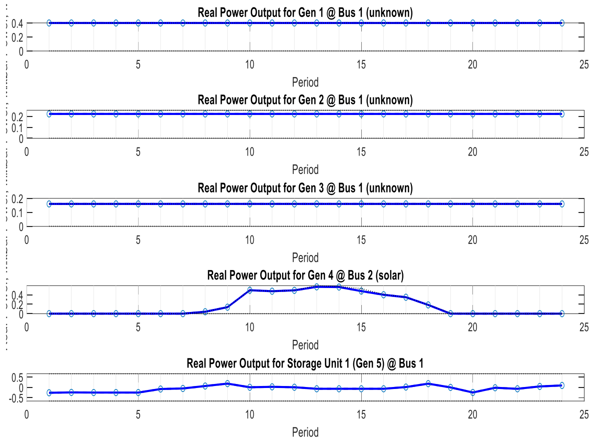

Figure 8: Showing the generational profile under improved load conditions.

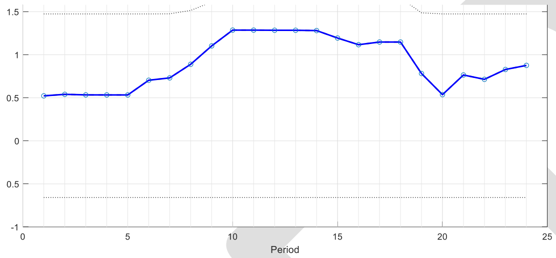

Figure 10: Showing the improved average daily load profile in MW

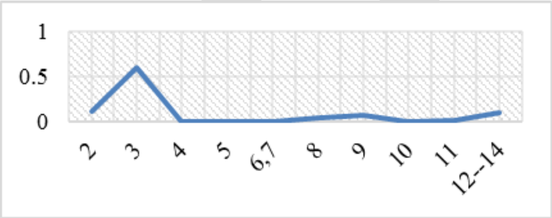

Figure 9: Showing the storage ramping costs in USD/Mwh during the planning period

For the low load scenario characterised by plant capacity factor of 26.43% and load factor of 70%. Two generators loaded to their full capacity was need to provide for the bulk of the load, the small load changes were economically handled by the energy storage system with limited support from the solar PV. The late arrival of PV to a network already supplied by diesel generations did not consider such direct replacement of the thermal generation by the PV. The ramping costs associated with this action were significant and this option was not considered by the model. This was necessary to void ramping and shut down costs.

During the case of increased loading, the plant capacity factor of 56.2% and load factor of 75% were achieved. The increase in the PV generation was matching the load growth and thereby the extra load was served by extra generation. This has demonstrated that for a committed thermal generation, it is not economical to directly replace it with PV generation. In this study, it has been shown that the extra load matching the extra generation from the PV supply yielded a better economic returns.

In both load scenarios, the selected diesel generators were loaded at their best efficiencies which was at their full load, as presented in [14]. The least cost option for the load changes was always chosen by the model and it is clear that the storage energy system had the lowest cost for any load changes. According to [15] fluctuating renewables increased ramping costs of back up generations and the ESS presents important cheaper alternatives [16] [17].

6 CONCLUSION.

In conclusion, the study confirms that the hybrid mode of operation is more economical as compared to only thermal units operation as presented in [9], [18], [16] and [14] among others.

In the hybrid mode backed up by flexible thermal generation or storage where PV availability is limited to certain periods of the day, the extra generation needs to be absorbed preferably by extra loading as opposed to reducing the output of the other flexible committed generations. For this particular case, the study shows that such action attracts extra costs which can affect the uptake of renewable energy.

In addition, the study has shown that better results can be obtained with improved plant capacity factors and therefore it is important to consider the economic gains for hybrids presented in [19] in context of the network load to avoid over optimistic results.

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