Design and Analysis of a Hybrid Power System for Western Libya

By

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Presentation Outline

1- Objectives

2- Introduction

3- Steady-state Stability of The power Grid in Western Libya

4- Sizing of A hybrid power system for Bani Walid

5- Impact of A large-scale PV System with ESS and Generator sets into A distribution Network in Bani Walid

6- Conclusion and future work

1- Objectives

(1) Propose a hybrid power system for use near Bani Walid Libya to provide reliable electricity.

(2) Analyze steady state stability of Bani Walid power grid using the real power grid data and loads in Bani Walid, Libya.

(3) Complete a sizing of the hybrid power system to suit the proposed site at Bani Walid and analyze the economic and technological feasibility of the system if battery storage were employed.

(4) Study the impact of hybrid grid-connected with a large scale PV system onto a distribution network in Bani Walid, as well as improve its stability.

(5) Contribute to the enhancement, increase and refocus of energy production across western Libya through the application of hybrid energy-producing systems and by exploiting the benefits of local renewable energy systems in cities like Bani Walid.

2- Introduction

(1) Hybrid Power Systems

(2) Libyan Energy Production

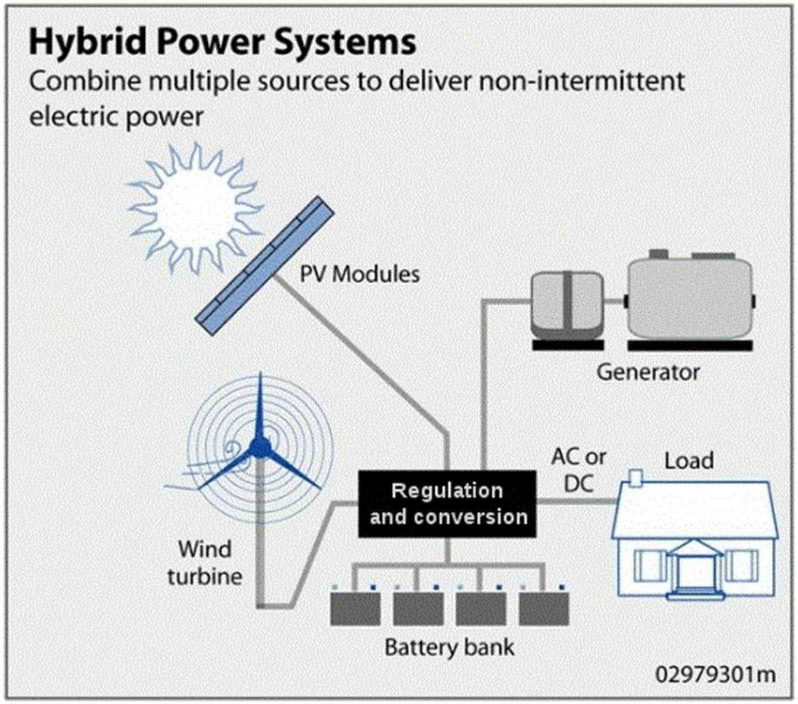
(3) Renewable Power Sources in Libya

(4) Selected Power Grid in Western Libya

(5) Tools that are used in this thesis for simulation and calculations

2- Introduction

(1) Hybrid Power Systems

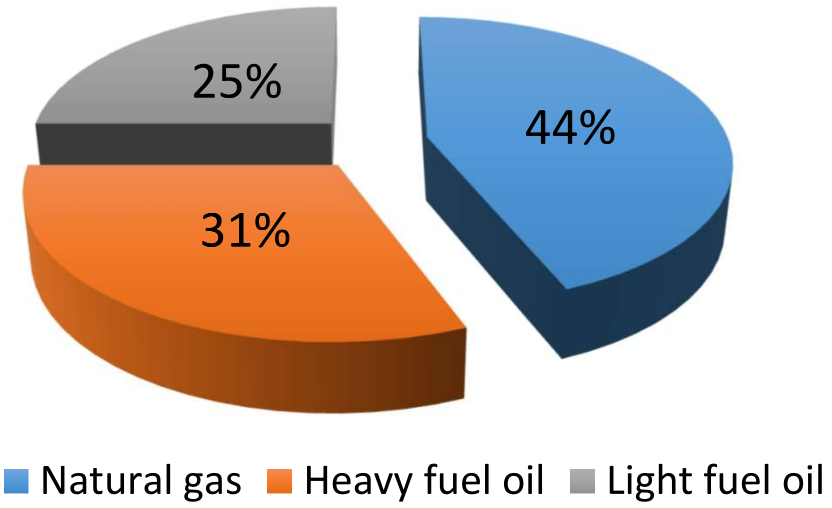


Hybrid Power Systems

Combine multiple sources to deliver non-intermittent electric power

2- Introduction

(2) Libyan Energy Production

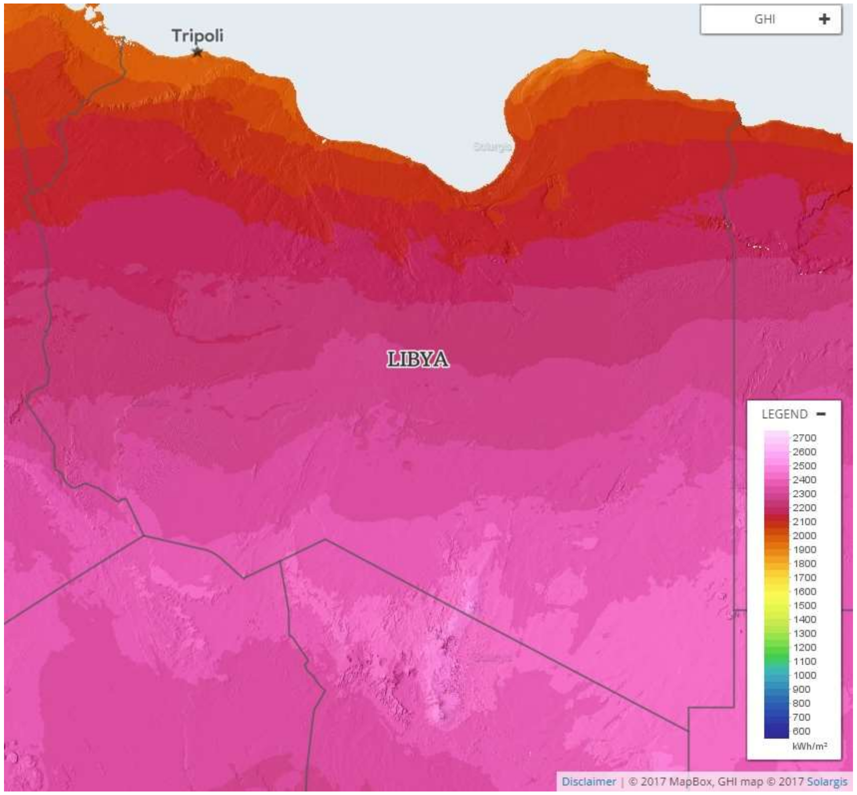


2- Introduction

(3) Renewable Power Sources in Libya

(a) Libya’s PV Systems

Libya is hot, dry and sunny climate ideal for solar power production



(3) Renewable Power Sources in Libya

(a) Libya's PV Systems

Although renewable energy in Libya has been used since 1970s , it has been used only for small applications

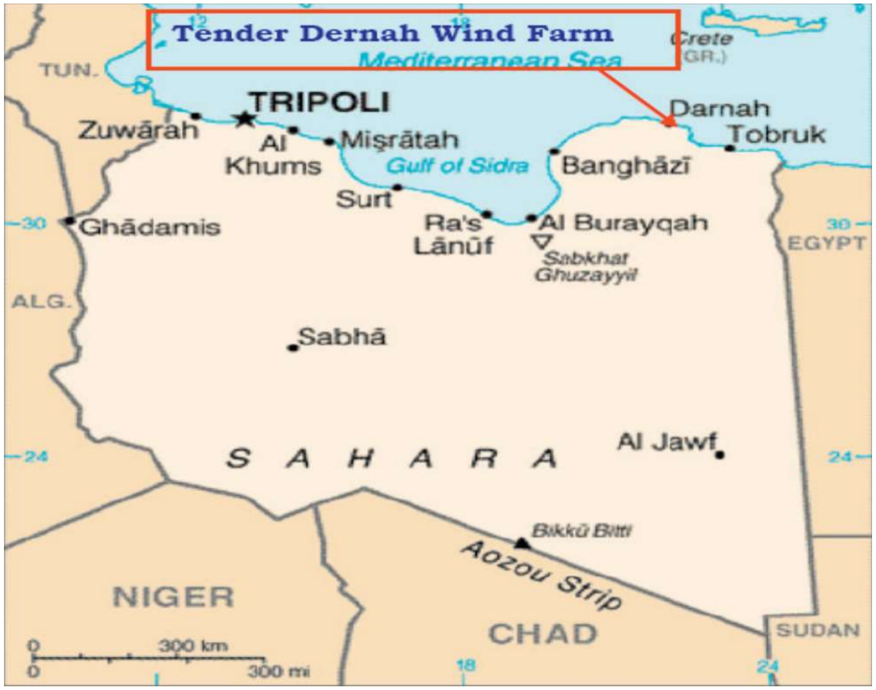
PV Systems and kWp in Libya to 2012

PV	kWp
PV (rural power)	725
PV (water pumps)	120
GPTC	850
Almadar	1500
Libyana	330
Oil Comp	120
Other	10
Total PV (communication systems)	2810
PV (streetlights)	1125
Centralized PV system	110
PV (rooftop systems)	30

(3) Renewable Power Sources in Libya

(b) Libya’s wind energy

Derna 60 MW wind farm



2- Introduction

(4) Selected power grid in Western Libya is Bani Walid power grid.

2- Introduction

(5) Tools that are used in this thesis for simulation and calculations

(a) PowerWorld Simulator (PWS)

(b) Hybrid Optimization Model for Electrical Renewable (HOMER) ver. 2.68

(c) AutoCAD 2015

which is a software application for computer-aided design and drafting. The software supports both 2D and 3D formats

(d) Electrical Transient Analysis Program (ETAP) ver. 16

3- Steady-state Stability of The power Grid in Western Libya

(1) Power Flow Solution

- (a) At Average Loads
- (b) At Peak Loads

(2) Q-V Curve Analysis

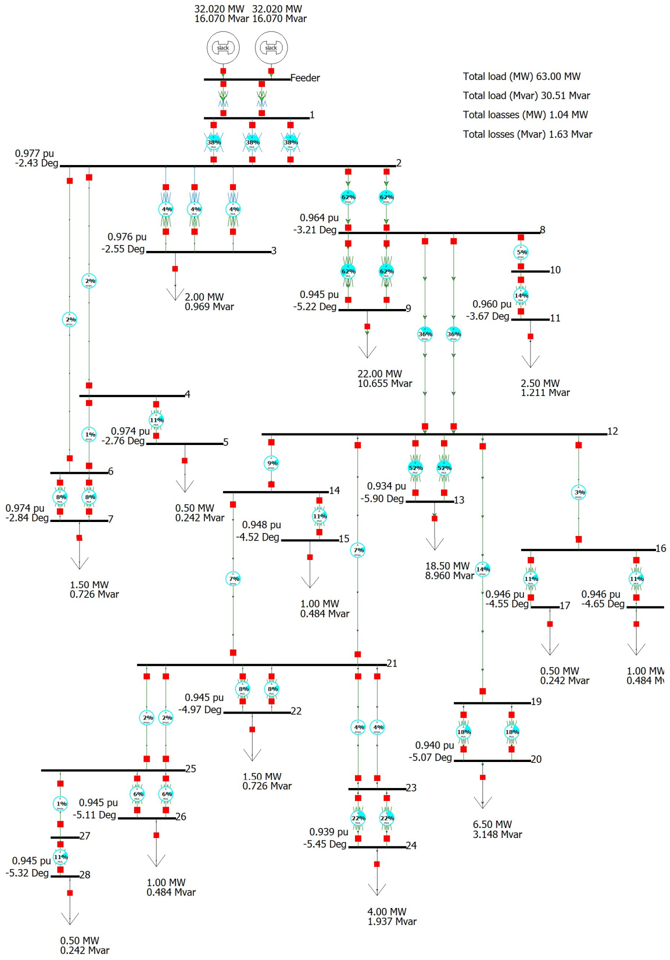
(3) Improvement of Power Flows of The power grid

3- Steady-state Stability of The power Grid in Western Libya

(1) Power Flow Solution

(a) At Average max Loads

Bus Number	Load Name	Nom kV	PU Volt	Load MW	Load Mvar
3	Bani Walid	11.00	0.976	2.00	0.969
5	Eshmikh	11.00	0.974	0.50	0.242
7	Tininai	11.00	0.974	1.50	0.726
9	Al Soof	11.00	0.945	22.00	10.655
11	Boyot Al Shabab	11.00	0.960	2.50	1.211
13	Khermani	11.00	0.934	18.50	8.960
15	Foguha	11.00	0.948	1.00	0.484
17	Weshtata	11.00	0.946	0.50	0.242
18	Weshtata	11.00	0.946	1.00	0.484
20	Shemalya	11.00	0.940	6.50	3.148
22	Sof Al Jeen	11.00	0.945	1.50	0.726
24	Al Mardom	11.00	0.939	4.00	1.937
26	Saddadah	11.00	0.945	1.00	0.484
28	Gerza	11.00	0.945	0.50	0.242

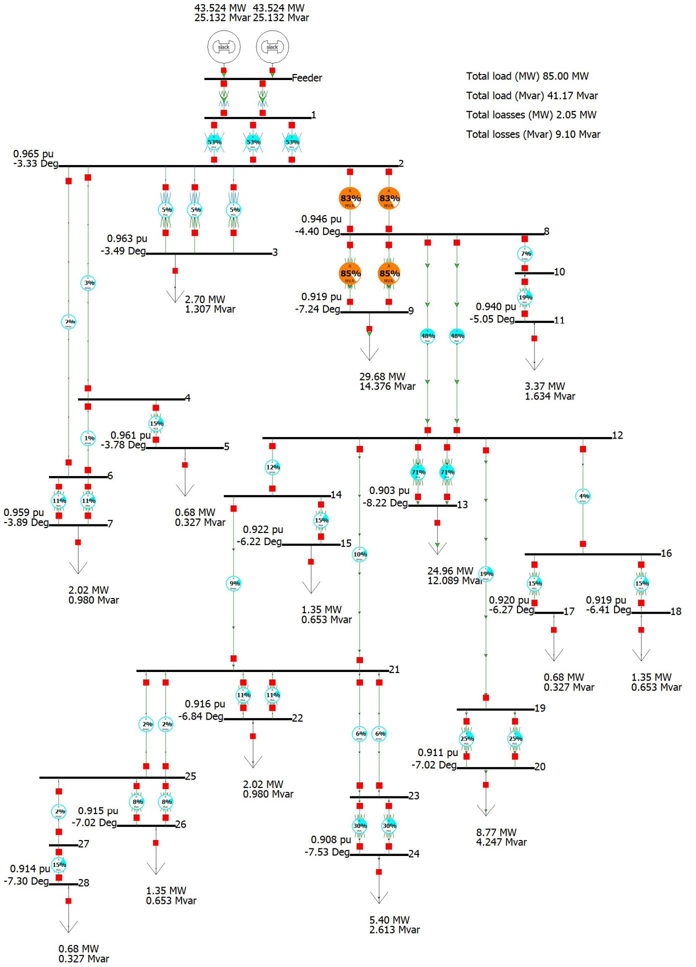


3- Steady-state Stability of The power Grid in Western Libya

(1) Power Flow Solution

(b) At Peak Loads

Bus Number	Load Name	Nom kV	PU Volt	Load MW	Load Mvar
3	Bani Walid	11.00	0.963	2.698	1.307
5	Eshmikh	11.00	0.961	0.675	0.327
7	Tininai	11.00	0.959	2.024	0.980
9	Al Soof	11.00	0.919	29.683	14.376
11	Boyot Al Shabab	11.00	0.940	3.373	1.634
13	Khermani	11.00	0.903	24.960	12.089
15	Foguha	11.00	0.922	1.349	0.653
17	Weshtata	11.00	0.920	0.675	0.327
18	Weshtata	11.00	0.919	1.349	0.653
20	Shemalya	11.00	0.911	8.770	4.247
22	Sof Al Jeen	11.00	0.916	2.024	0.980
24	Al Mardom	11.00	0.908	5.397	2.613
26	Saddadah	11.00	0.915	1.349	0.653
28	Gerza	11.00	0.914	0.675	0.327



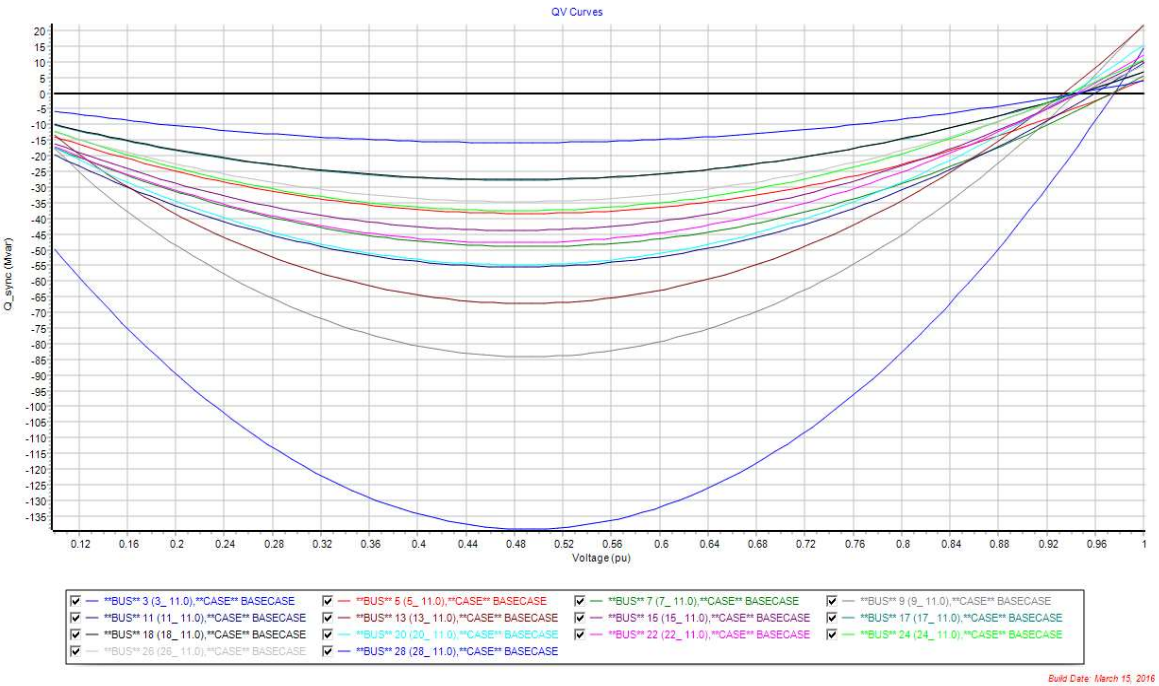
3- Steady-state Stability of The power Grid in Western Libya

(2) Q-V Curve Analysis

All load buses are stable

Bus 3 more stable

While bus 28 is less stable



Q-V Curve Plot

3- Steady-state Stability of The power Grid in Western Libya

(2) Q-V Analysis

Bus No	Nom kV	V at Q0	Vmax	Q at VMax	Qinj at Vmax	V at Qmin	Qmin	Vmin	Q at Vmin
3	11.00	0.98	1.0000	14.31	14.31	0.4958	-139.18	0.1000	-49.86
5	11.00	0.97	1.0000	4.17	4.17	0.4945	-38.43	0.1000	-13.89
7	11.00	0.97	1.0000	5.53	5.53	0.4936	-48.98	0.1000	-17.32
9	11.00	0.94	1.0000	21.90	21.90	0.4946	-84.15	0.1000	-17.66
11	11.00	0.96	1.0000	9.81	9.81	0.4797	-55.48	0.1000	-19.63
13	11.00	0.93	1.0000	21.43	21.43	0.4840	-67.09	0.1000	-13.33
15	11.00	0.95	1.0000	10.30	10.30	0.4778	-43.82	0.1000	-16.04
17	11.00	0.95	1.0000	6.75	6.75	0.4764	-27.77	0.1000	-10.19
18	11.00	0.95	1.0000	6.85	6.85	0.4756	-27.62	0.1000	-9.95
20	11.00	0.94	1.0000	15.32	15.32	0.4802	-54.81	0.1000	-17.44
22	11.00	0.94	1.0000	12.17	12.17	0.4846	-47.75	0.1000	-17.03
24	11.00	0.94	1.0000	10.75	10.75	0.4790	-37.54	0.1000	-12.21
26	11.00	0.95	1.0000	8.74	8.74	0.4751	-34.66	0.1000	-12.46
28	11.00	0.95	1.0000	3.98	3.98	0.4752	-15.82	0.1000	-5.71

3- Steady-state Stability of The power Grid in Western Libya

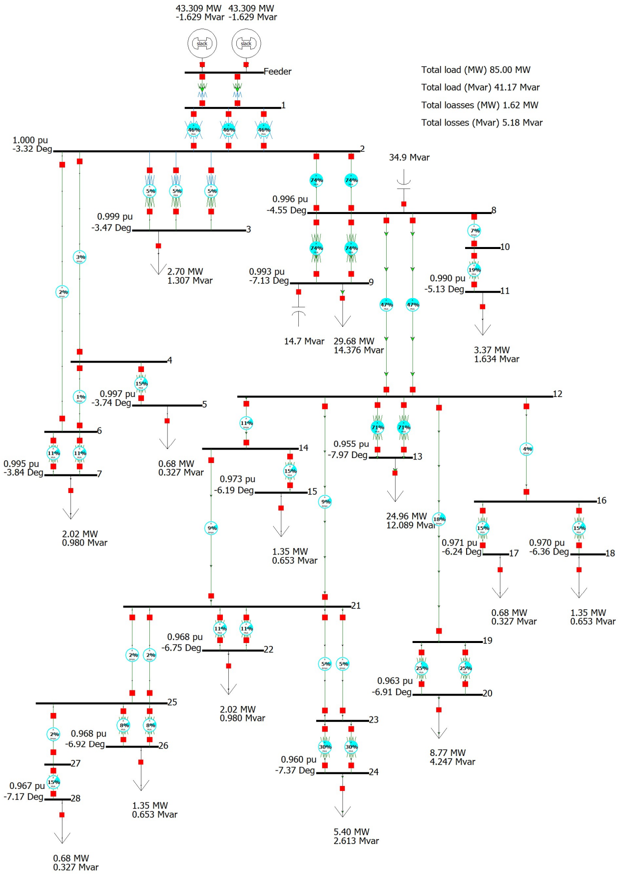
(3) Improvement of Power Flows of The power Grid

Power flow results before adding shunt capacitor

Branch	From bus No	To bus No	Loading MW (%)	Loading Mvar (%)	Loading MVA (%)	Total system losses (MW)	Total system losses (Mvar)
Lines	2	8	74	39	83	2.05	9.1
transformers	8	9	75	41	85		

Power flow results after adding shunt capacitor

Branch	From bus No	To bus No	Loading MW (%)	Loading Mvar (%)	Loading MVA (%)	Total system losses (MW)	Total system losses (Mvar)
Lines	2	8	74	5	74	1.62	5.18
transformers	8	9	74	3	74		



3- Steady-state Stability of The power Grid in Western Libya

3- Improvement of Power Flows of The power Grid

Bus No	Name	Nom kV	PU Volt	Load MW	Load Mvar
3	Bani Walid	11.00	0.999	2.698	1.307
5	Eshmikh	11.00	0.997	0.675	0.327
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11	Boyot Al Shabab	11.00	0.990	3.373	1.634
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20	Shemalya	11.00	0.963	8.770	4.247
22	Sof Al Jeen	11.00	0.968	2.024	0.980
24	Al Mardom	11.00	0.960	5.397	2.613
26	Saddadah	11.00	0.968	1.349	0.653
28	Gerza	11.00	0.967	0.675	0.327

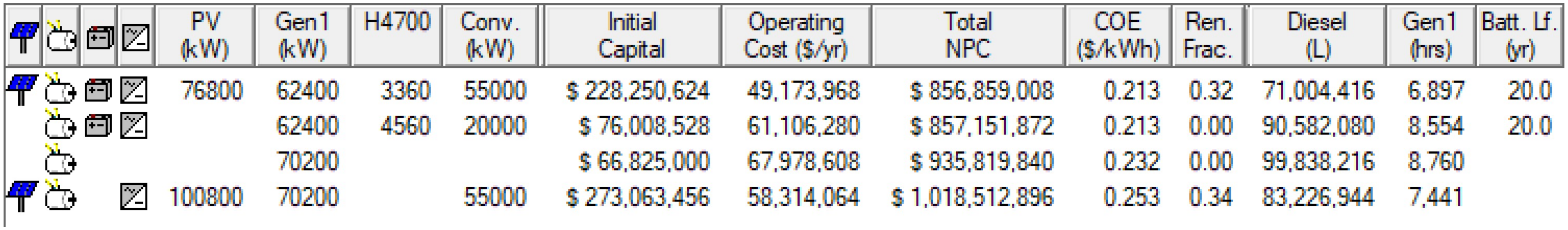
4- Sizing of A hybrid power system for Bani Walid

(1) Optimized System and Economic Comparison Between The optimized Power System and The other ranked cases.

(2) Sensitivity Analysis

4- Sizing of A hybrid power system for Bani Walid

(1) Optimized System and Economic Comparison



PV (kW)	Gen1 (kW)	H4700	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)	Batt. Lf. (yr)
76800	62400	3360	55000	$ 228,250,624	49,173,968	$ 856,859,008	0.213	0.32	71,004,416	6,897	20.0
	62400	4560	20000	$ 76,008,528	61,106,280	$ 857,151,872	0.213	0.00	90,582,080	8,554	20.0
	70200			$ 66,825,000	67,978,608	$ 935,819,840	0.232	0.00	99,838,216	8,760	
100800	70200		55000	$ 273,063,456	58,314,064	$ 1,018,512,896	0.253	0.34	83,226,944	7,441	

- Battery storage minimize COE to the lowest value (0.213 $/kWh)
- With including Renewable Energy, the percent worth is $78,960,928 and the simple payback is 9.02 years.

Optimized System

PV	76,800 kW
Generator sets	62,400 kW
Inverter	55,000 kW
Rectifier	55,000 kW
Batteries	3,360

4- Sizing of A hybrid power system for Bani Walid

(2) Sensitivity Analysis

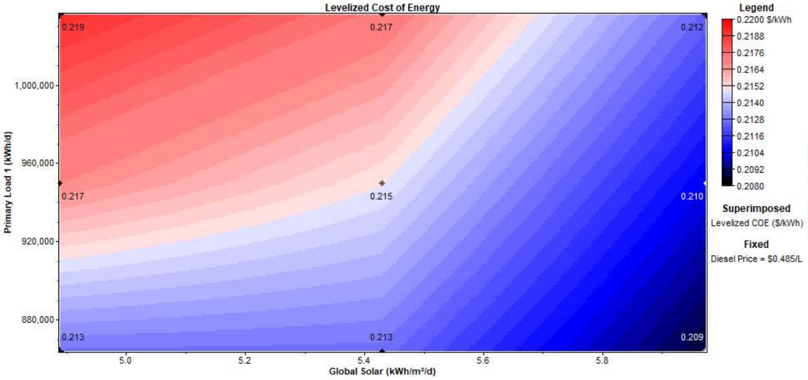
Sensitivity Variable Inputs

Diesel price	0%	10%	20%	30%
Loads	0%	10%	20%	
Solar radiation	-5%	0%	5%	

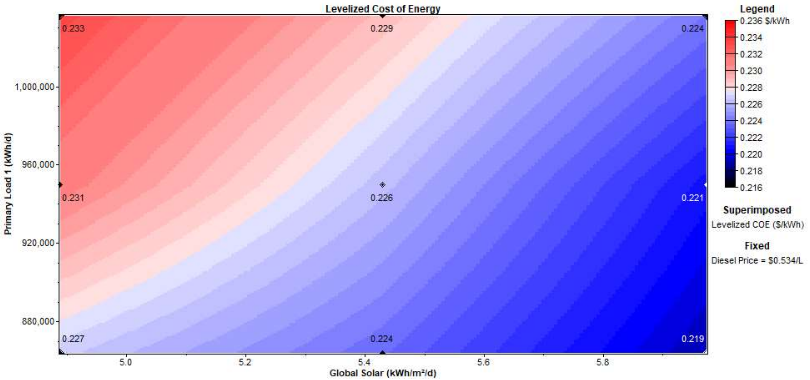
4- Sizing of A hybrid power system for Bani Walid

(2) Sensitivity Analysis

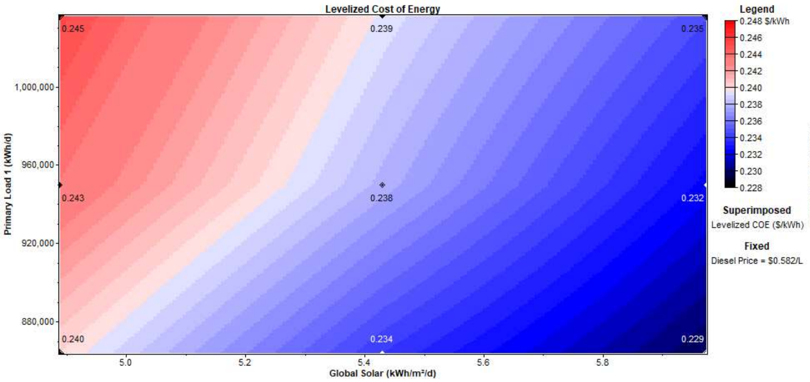
(a) Levelized cost of energy (COE)



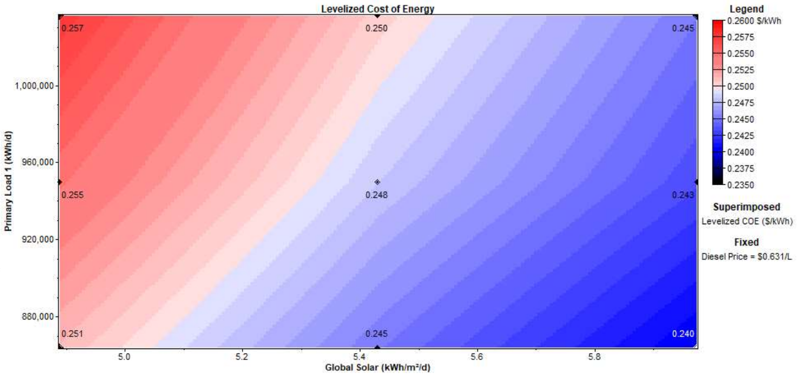
At load sensitivities (0, 10, and 20%) and diesel price 0%



At load sensitivities (0, 10, and 20%) and diesel price 10%



At load sensitivities (0, 10, and 20%) and diesel price 20%

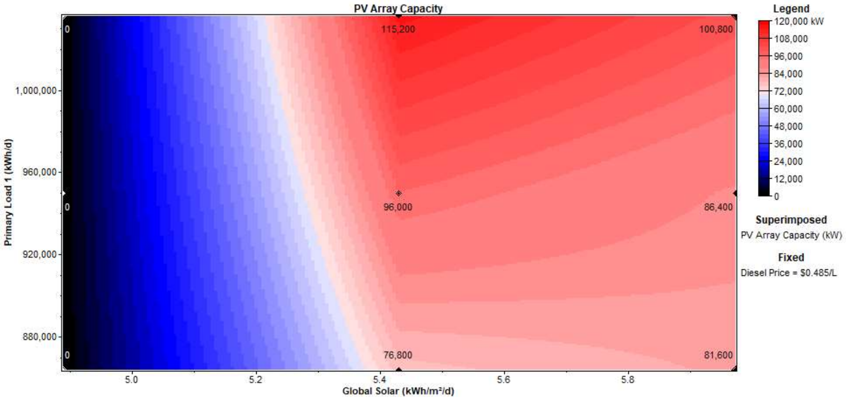


At load sensitivities (0, 10, and 20%) and diesel price 30%

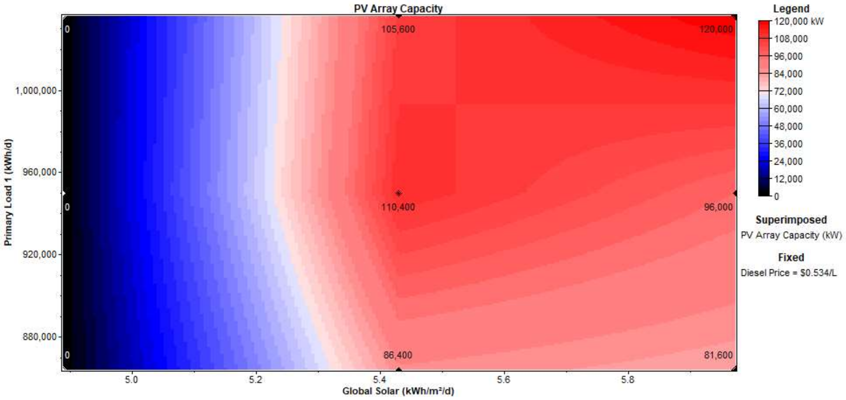
4- Sizing of A hybrid power system for Bani Walid

(2) Sensitivity Analysis

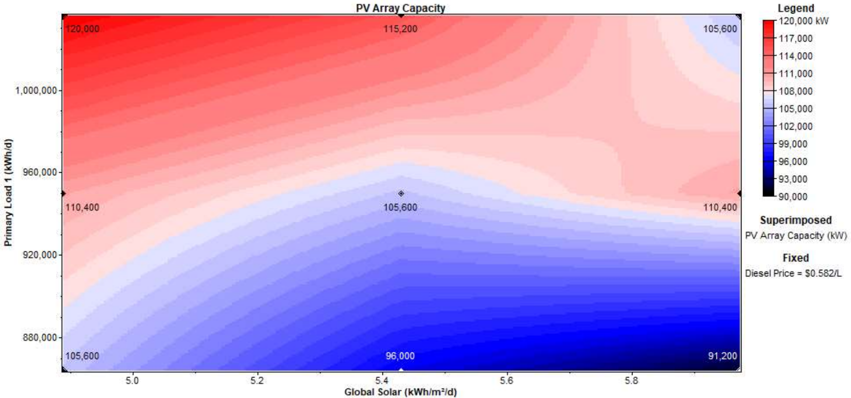
(b) Optimal PV system



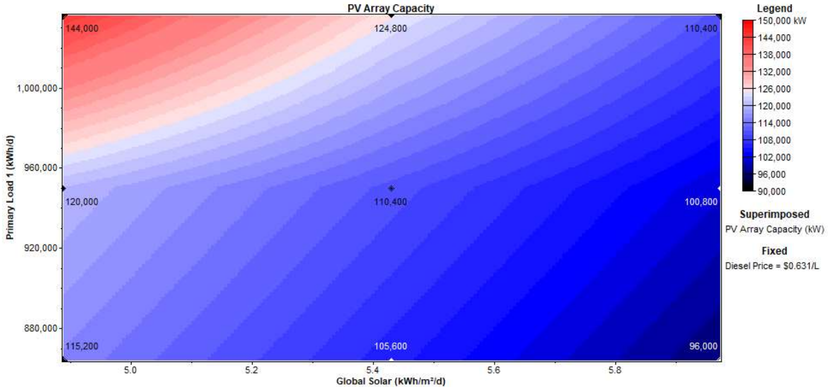
At load sensitivities (0, 10, and 20%) and diesel price 0%



At load sensitivities (0, 10, and 20%) and diesel price 10%



At load sensitivities (0, 10, and 20%) and diesel price 20%

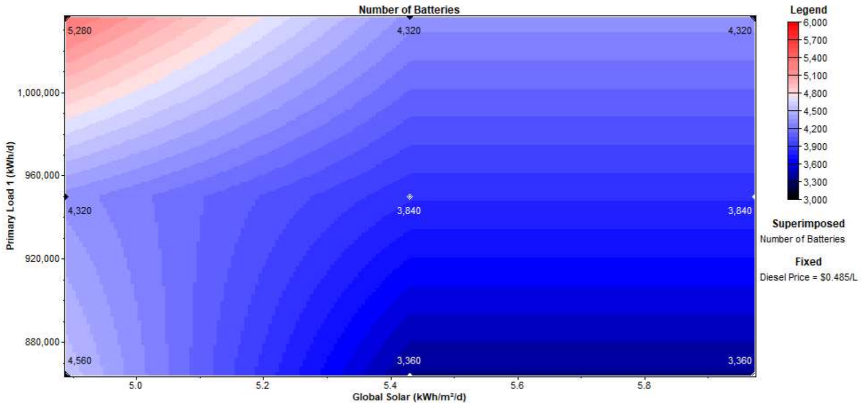


At load sensitivities (0, 10, and 20%) and diesel price 30%

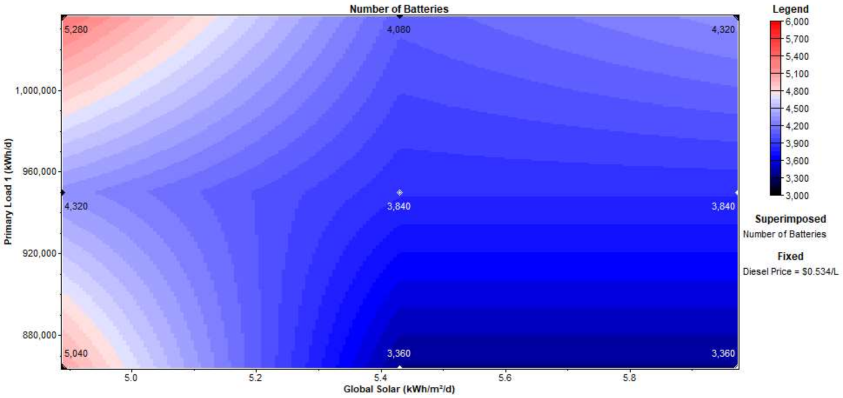
4- Sizing of A hybrid power system for Bani Walid

(2) Sensitivity Analysis

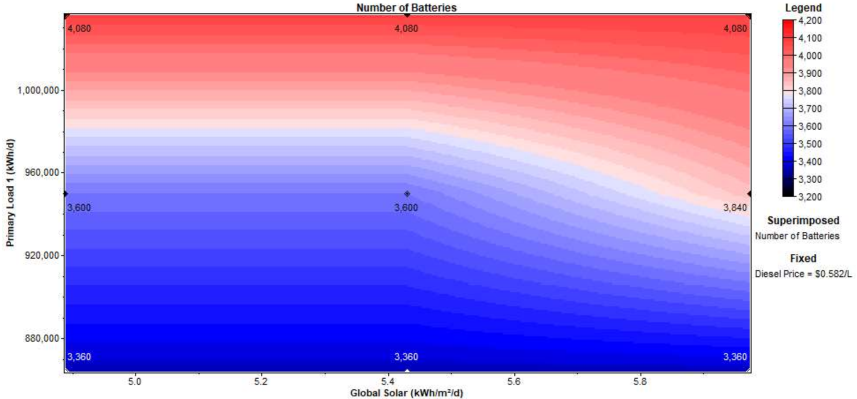
(C) Optimal battery storage



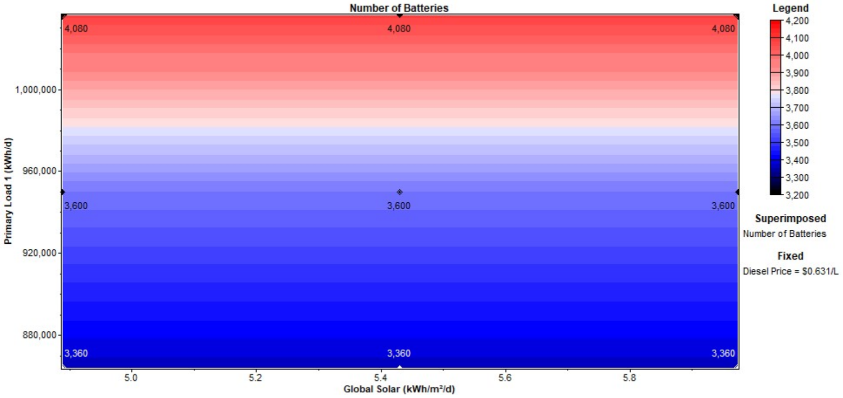
At load sensitivities (0, 10, and 20%) and diesel price 0%



At load sensitivities (0, 10, and 20%) and diesel price 10%



At load sensitivities (0, 10, and 20%) and diesel price 20%



At load sensitivities (0, 10, and 20%) and diesel price 30%

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(1) An Overview of The designed Hybrid power system

(2) PV Array Calculations and The required Area for PV Modules

(3) Field design for The proposed PV System

(4) Power Flow Analysis of The designed Hybrid Power System

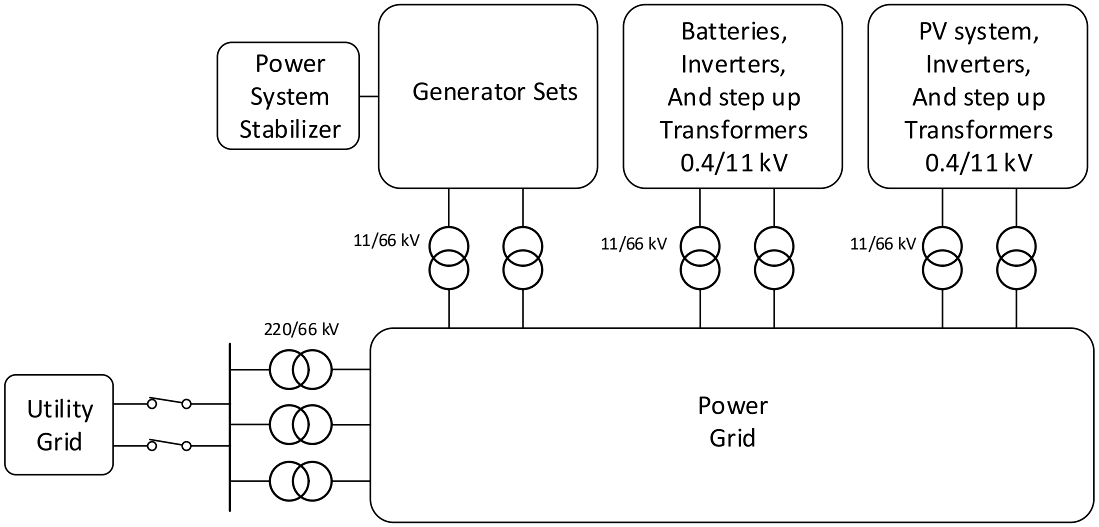
(5) Control of Power Flow

(6) Contingency Analysis

(7) Transient Stability Analysis of The designed Hybrid Power System

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(1) An Overview of the designed hybrid power system



Block diagram of the designed hybrid power system

(2) PV Array Calculations and The required Area for PV Modules

FF = 78.29

η = 19.03 %

$$FF = \frac{P_{max}}{I_{SC}V_{OC}}$$

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_{SC}\ V_{OC}\ FF}{P_{in}}$$

Where P_{in} is the light power incident on the PV panel

PV Parameters

Temperature (NOCT) [°C]	44 °C
Temp. coefficient of P_{max} [%/°C]	-0.29 %/°C
Temp. coefficient of V_{oc} [V/°C]	-0.131 V/°C
Temp. coefficient of I_{sc} [mA/°C]	1.76 mA/°C
Open circuit voltage (V_{oc}) [V]	52.4 V
Max. power voltage (V_{mp}) [V]	43.6 V

(2) PV Array Calculations and The required Area for PV Modules

Maximum number of modules per string is 14 modules

Minimum number of modules per string is 12 modules

$$V_{oc@T} = V_{oc@T_r} * \left(1 + \frac{\beta V_{oc} * (T - T_r)}{100}\right)$$

$$V_{mp@T} = V_{mp@T_r} * \left(1 + \frac{\beta V_{mp} * (T - T_r)}{100}\right)$$

Maximum arrays can be connected in parallel

$$\frac{100\ kW}{0.24\ kW} = 416.67\ modules \approx 416\ modules$$

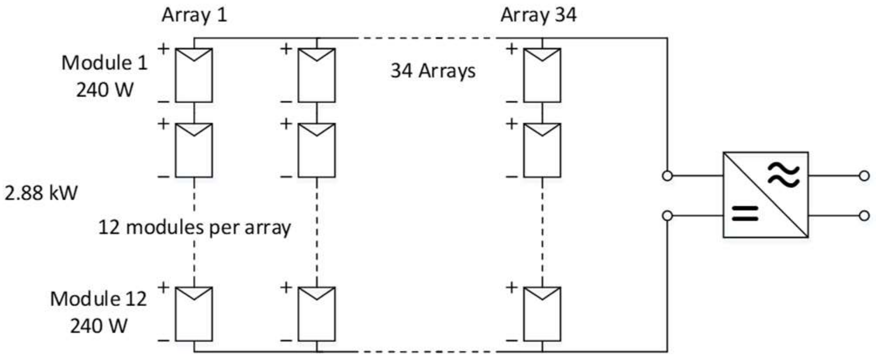
$$\frac{Modules\ per\ inverter}{Modules\ per\ strings} = \frac{416}{12} = 34.67 \quad \approx 34\ \text{strings}$$

The output power of 35 strings exceeds the maximum power of the installed inverter (100 kW), therefore the selected strings is 34 strings

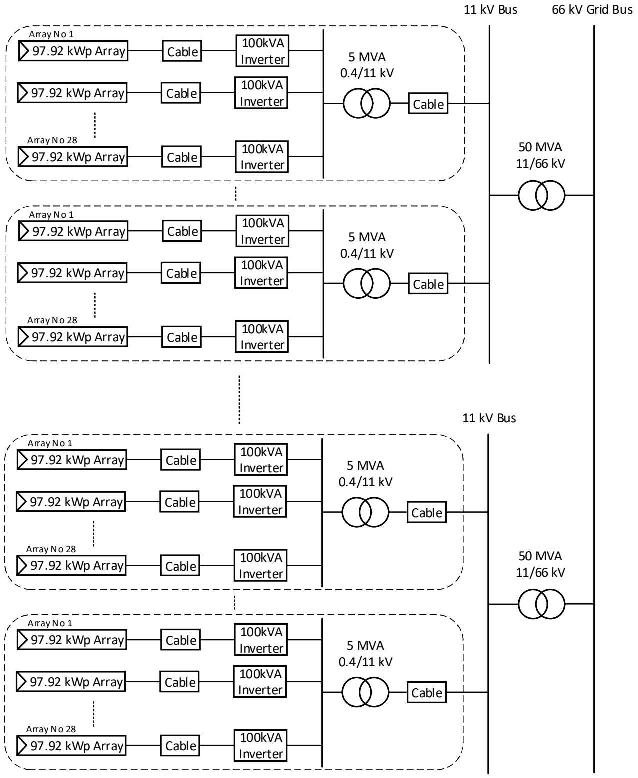
The number of modules per one inverter will be $34 * 12 = 408\ modules$

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(2) PV Array Calculations and The required Area for PV Modules



Configuration of PV arrays



Circuit diagram of the 76.8 MW PV power station

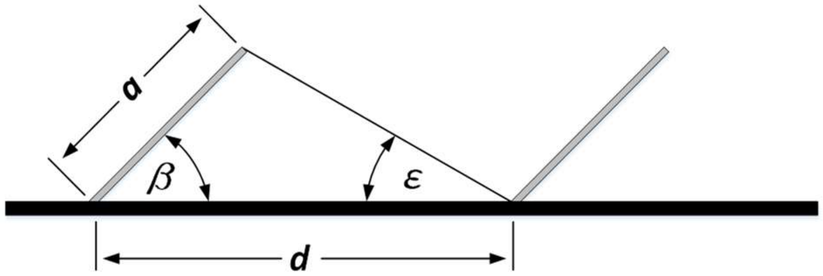
5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

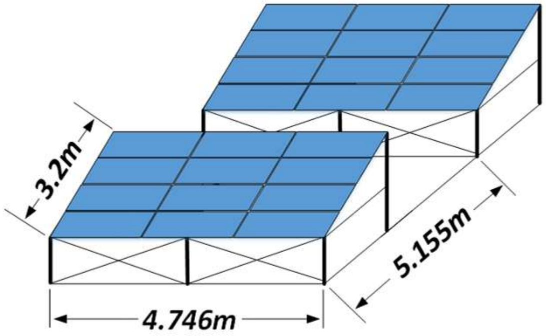
(2) PV Array Calculations and The required Area for PV Modules

$$\frac{d}{a} = \cos\beta + \frac{\sin\beta}{\tan\varepsilon}$$

$$\varepsilon = 90^\circ - \delta - \emptyset$$

Where ε can be calculated by the geographical latitude ∅ and the ecliptic angle $\delta = 23.5$



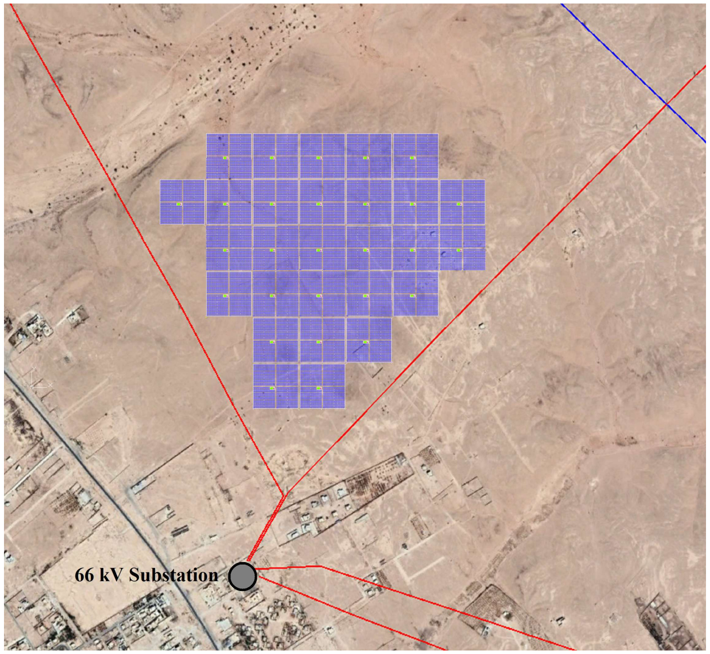


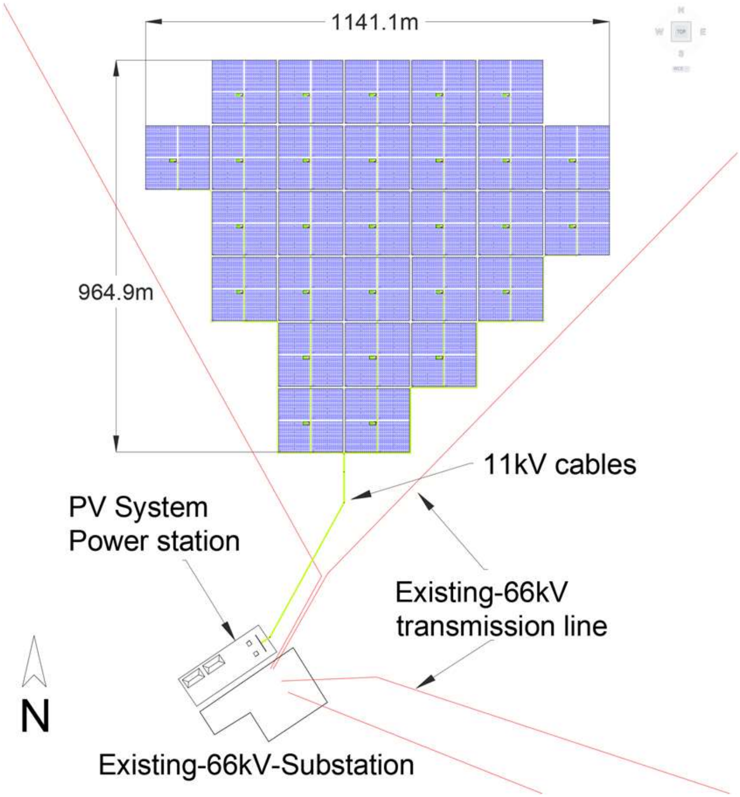
The required area for one PV array (2.88 kW) is 12.995 m^2, while the required area for one PV module with land is 24.466 m^2. The required area for one PV substation with land is 24,982.596 m^2.

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(3) Field design for the proposed PV System

Proposed location is at Latitude N31.8 and Longitude E14 which is in the north of Bani Walid valley and very close to a distribution station

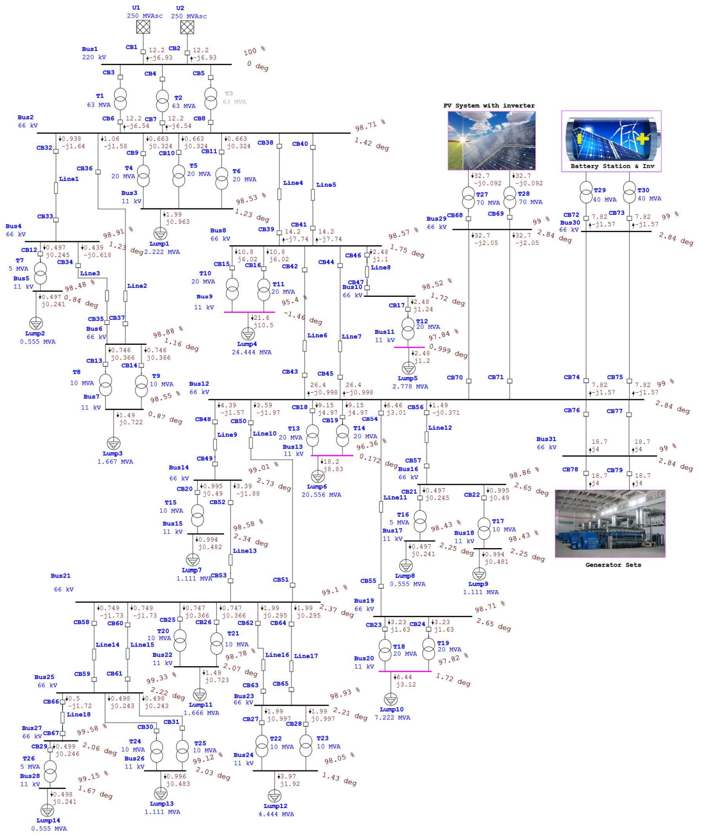




5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(4) Power Flow Analysis of The designed Hybrid Power System

Power flow results



ID	Load name	Terminal Bus	Nominal kV	Voltage% at average max load	Voltage % at peak load
Lump1	Bani Walid	Bus3	11	98.53	98.1
Lump2	Eshmikh	Bus5	11	98.48	97.89
Lump3	Tininai	Bus7	11	98.55	97.97
Lump4	Al Soof	Bus9	11	95.4	93.68
Lump5	Boyot Al Shabab	Bus11	11	97.84	97.09
Lump6	Khermani	Bus13	11	96.36	94.91
Lump7	Foguha	Bus15	11	98.58	97.92
Lump8	Weshtata	Bus17	11	98.43	97.73
Lump9	Weshtata	Bus18	11	98.43	97.73
Lump10	Shemalya	Bus20	11	97.82	96.94
Lump11	Sof Al Jeen	Bus22	11	98.78	98.01
Lump12	Al Mardom	Bus24	11	98.05	96.99
Lump13	Saddadah	Bus26	11	99.12	98.33
Lump14	Gerza	Bus28	11	99.15	98.22

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(5) Control of Power Flow

(a) Control of Power Flow Using Automatic Voltage-magnitude-regulating Transformer

Taps and Steps that are used in transformers in Libya

Power transformer	The number of steps			Tapping Step
	Step up	Step down	Total steps	
66/11 kV	8	8	17	Rated voltage* 1.25

ETAP calculates number of Taps and % step based on the following formula:

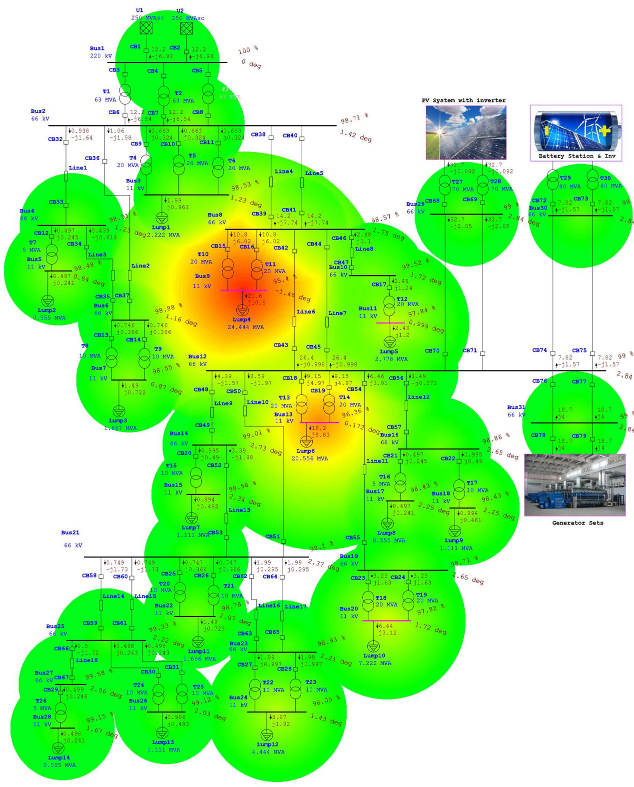
$$\#\ of\ Taps = 1 + \frac{\%Max\ Tap - \%Min\ Tap}{\%Step}$$

$$\%\ Step = \frac{\%Max\ Tap - \%Min\ Tap}{\#\ of\ Taps - 1}$$

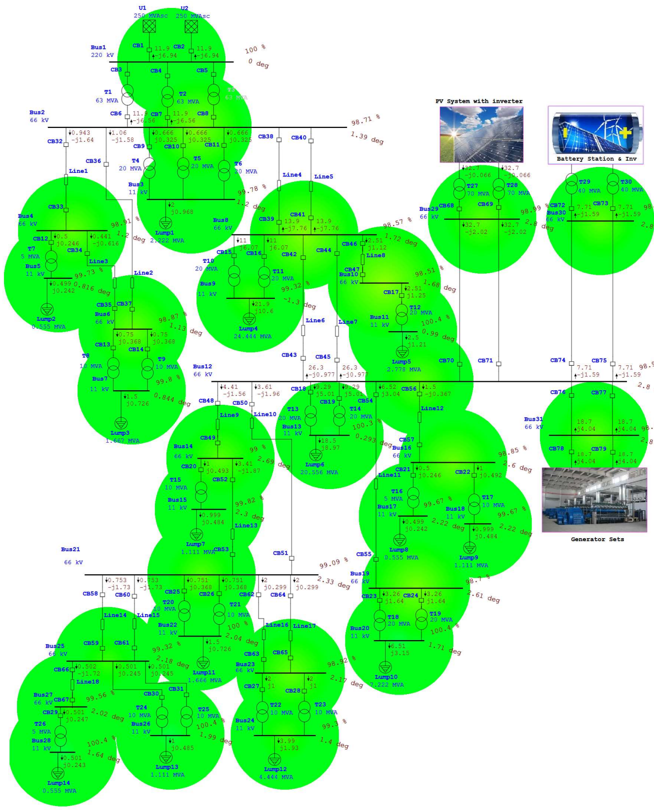
5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(5) Control of Power Flow

(b) Power flows solution at average max loads



Power flow at base case

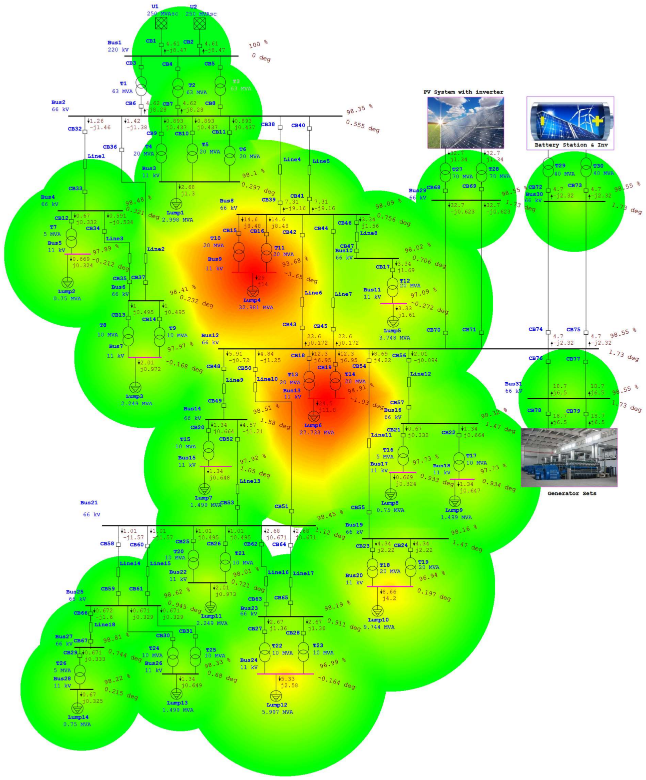


Power flow with automatic voltage regulator

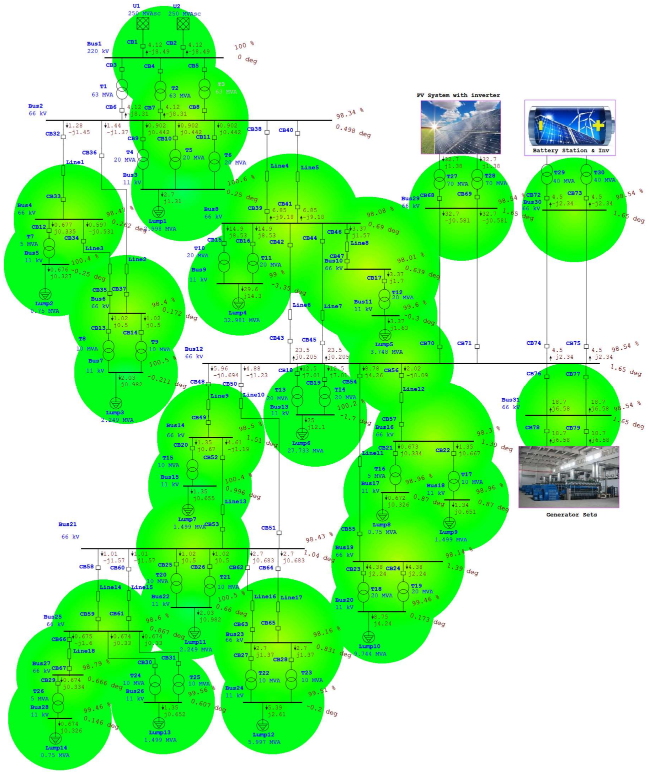
5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(5) Control of Power Flow

(c) Power flows solution at peak loads



Power flow at base case



Power flow with automatic voltage regulator

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(5) Control of Power Flow

Power flows solution at load buses after voltage regulation

ID	Load name	Bus ID	Nominal kV	Voltage% at average max load	Voltage % at peak load
Lump1	Bani Walid	Bus3	11	99.78	100.62
Lump2	Eshmikh	Bus5	11	99.73	100.41
Lump3	Tininai	Bus7	11	99.8	100.49
Lump4	Al Soof	Bus9	11	99.32	99
Lump5	Boyot Al Shabab	Bus11	11	100.36	99.6
Lump6	Khermani	Bus13	11	100.28	100.22
Lump7	Foguha	Bus15	11	99.82	100.44
Lump8	Weshtata	Bus17	11	99.67	98.96
Lump9	Weshtata	Bus18	11	99.67	98.96
Lump10	Shemalya	Bus20	11	100.35	99.46
Lump11	Sof Al Jeen	Bus22	11	100.03	100.52
Lump12	Al Mardom	Bus24	11	99.3	99.51
Lump13	Saddadah	Bus26	11	100.36	99.56
Lump14	Gerza	Bus28	11	100.4	99.46

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(6) Contingency Analysis

Loading Violations

N-1			No. of Loading Violations	Post Contingency Violations					
N. of Contingency	ID	Type	Xfmr	ID	Condition	Rating /limit	Post Contingency (%)	% Violation	Type
9	T10	Transformer	1	T11	Overloaded	20 MVA	130.08%	30.08%	Critical
10	T11	Transformer	1	T10	Overloaded	20 MVA	130.08%	30.08%	Critical
12	T13	Transformer	1	T14	Overloaded	20 MVA	108.33%	8.33%	Critical
13	T14	Transformer	1	T13	Overloaded	20 MVA	108.33%	8.33%	Critical

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(7) Transient Stability Analysis of the designed hybrid power system

(a) Control methods

All machines use Woodward UG-8 governor and IEEE Type AC4 exciter system as well as PSS Type PSS1A to help with system stability.

(b) Simulation results

① Trip of utility grid

② Trip of PV system

③ Three phase short circuit at Bus 1 results in tripping the utility grid

④ Three phase short circuit at Bus 29 results in tripping the PV system

⑤ Three phase short circuit at line 11 results in tripping the load No 10 (7.222 MVA)

(c) Power system stabilizer (PSS) performance during transient stability

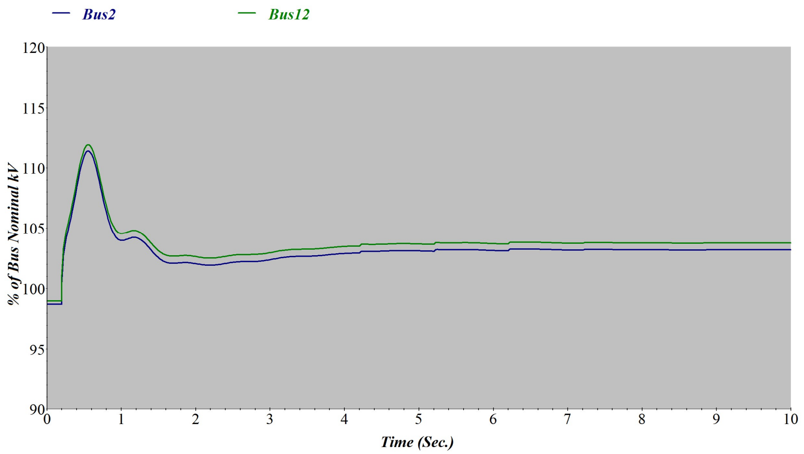
(d) The performance of automatic voltage-magnitude-regulating transformer

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

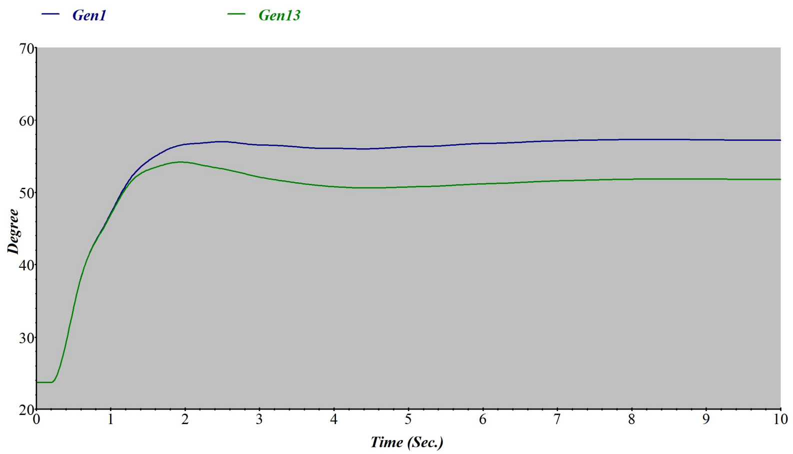
(7) Transient Stability Analysis of the designed hybrid power system

(b) Simulation results

① Trip of utility grid



Voltages at Bus 2 and Bus12



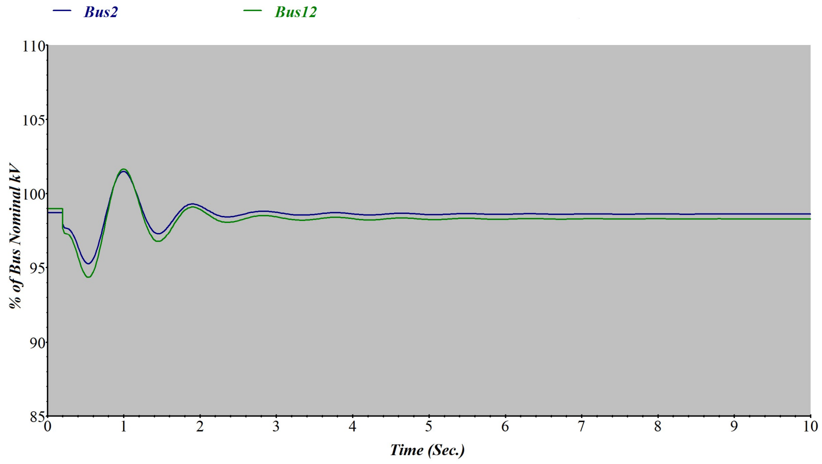
Generators absolute power angle

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

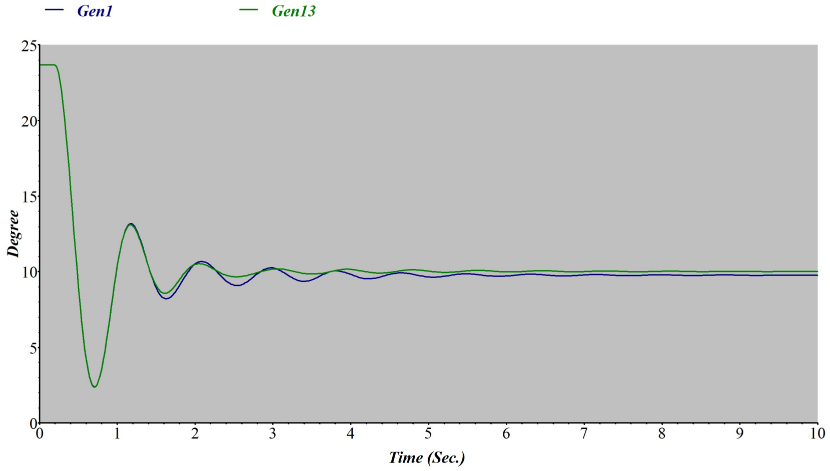
(7) Transient Stability Analysis of the designed hybrid power system

(b) Simulation results

② Trip of PV system



Voltages at Bus 2 and Bus12



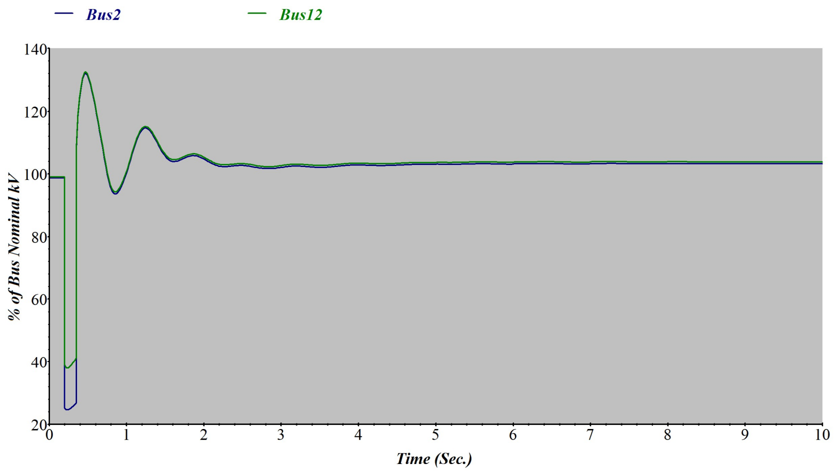
Generators absolute power angle

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

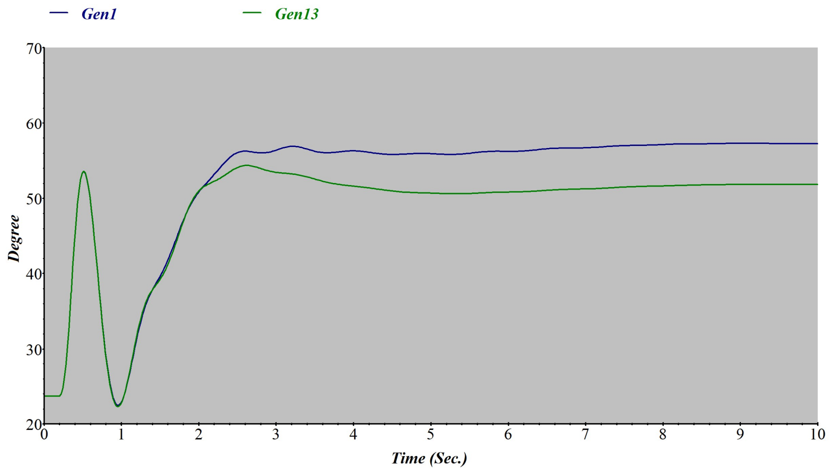
(7) Transient Stability Analysis of the designed hybrid power system

(b) Simulation results

③ Three phase short circuit at Bus 1 results in tripping the utility grid



Voltages at Bus 2 and Bus12



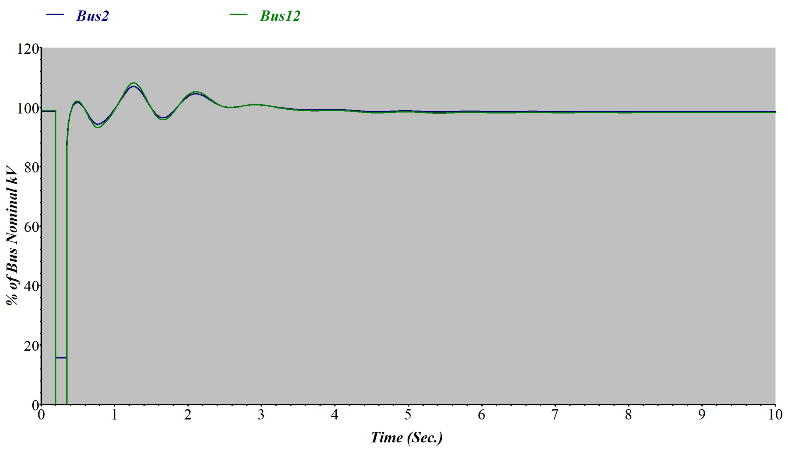
Generators absolute power angle

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

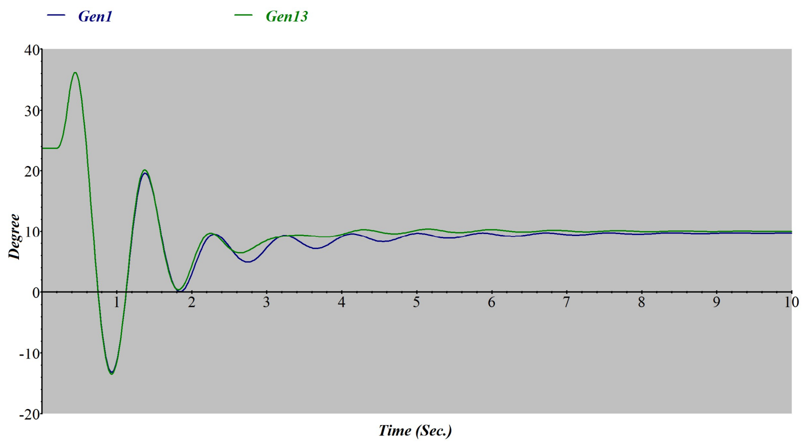
(7) Transient Stability Analysis of the designed hybrid power system

(b) Simulation results

④ Three phase short circuit at Bus 29 results in tripping the PV system



Voltages at Bus 2 and Bus12



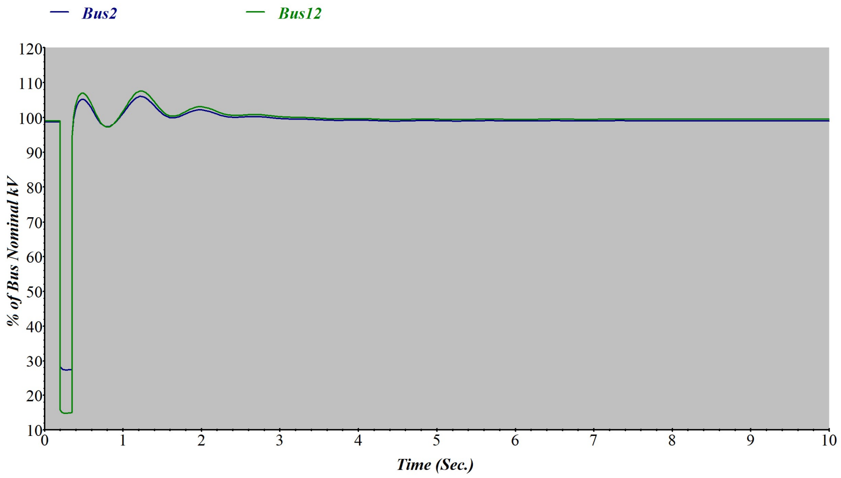
Generators absolute power angle

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

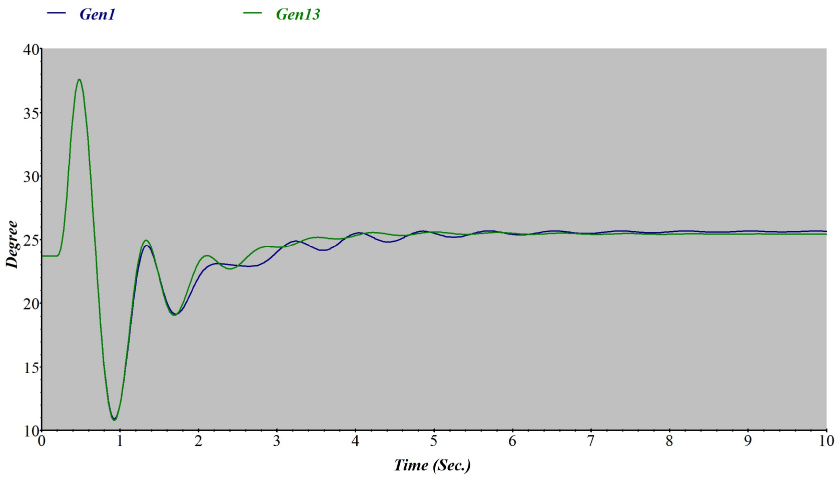
(7) Transient Stability Analysis of the designed hybrid power system

(b) Simulation results

⑤ Three phase short circuit at line 11 results in tripping the load No 10 (7.222 MVA)



Voltages at Bus 2 and Bus12

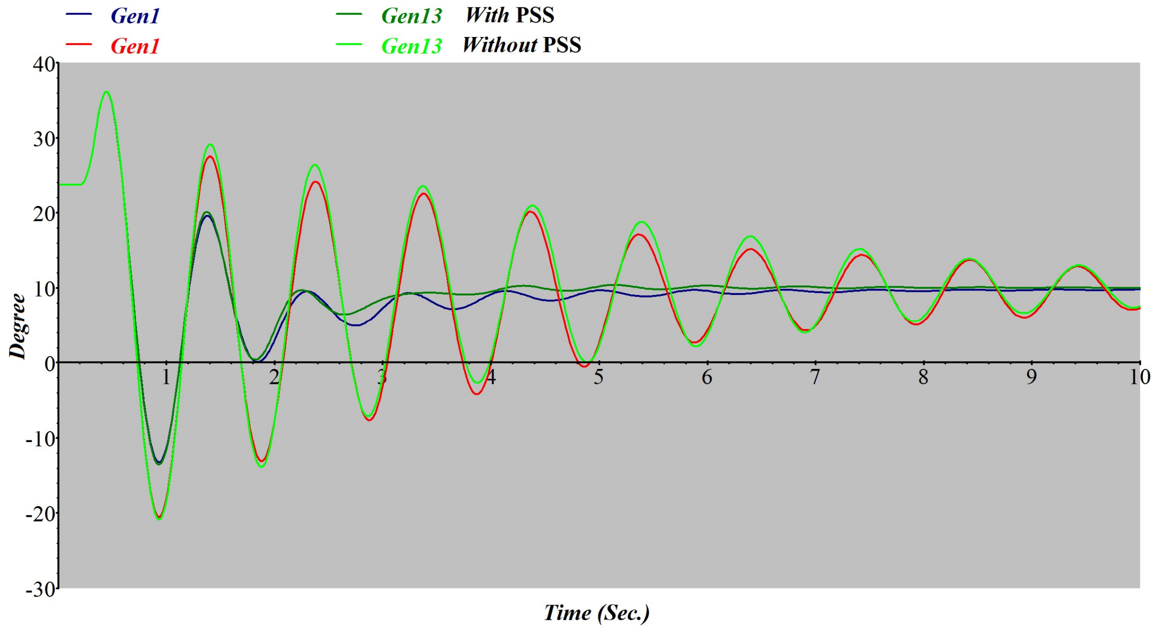


Generators absolute power angle

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(7) Transient Stability Analysis of the designed hybrid power system

(c) Power system stabilizer (PSS) performance during transient stability



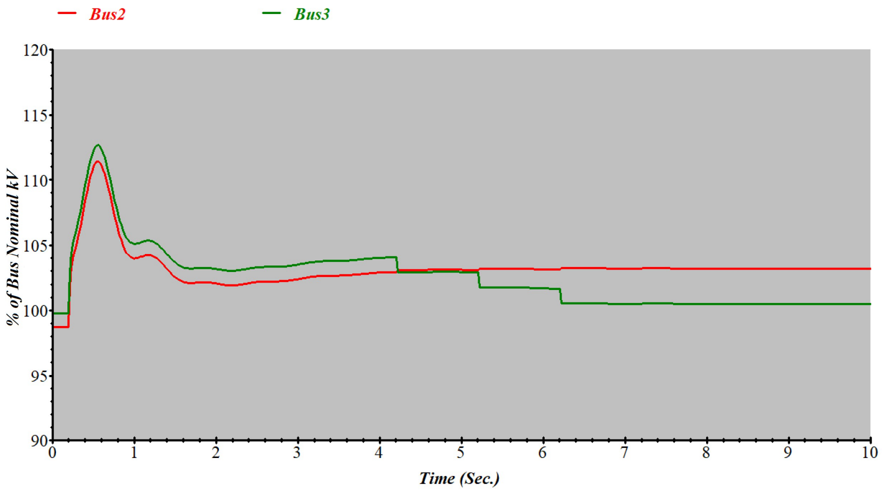
Generators absolute power angle with and without PSS

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

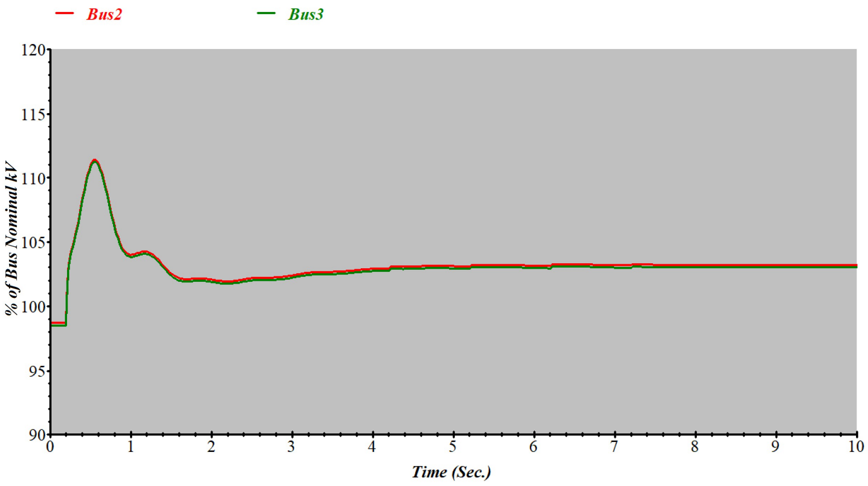
(7) Transient Stability Analysis of the designed hybrid power system

(d) The performance of automatic voltage-magnitude-regulating transformer

Trip of utility grid



Voltages at bus 2 and load bus 3 with automatic voltage regulation



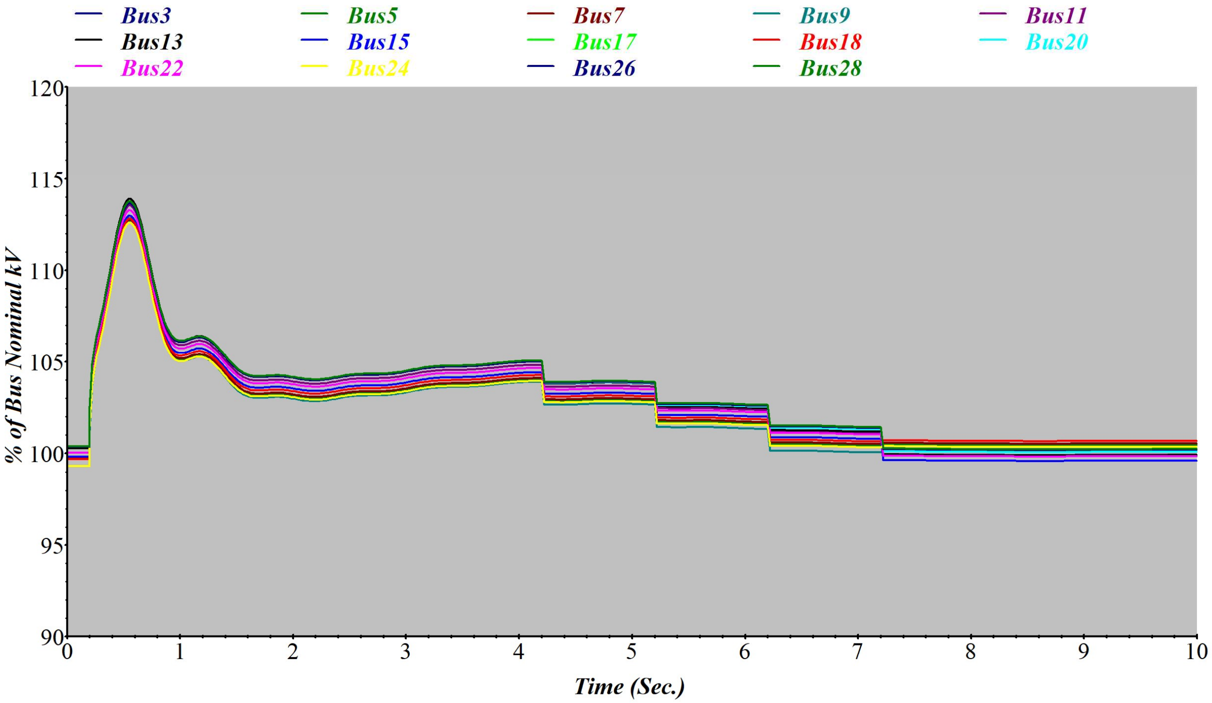
Voltages at bus 2 and load bus 3 without automatic voltage regulation

5- Impact of A large-scale PV System with ESS and Generators into A distribution Network in Bani Walid

(7) Transient Stability Analysis of the designed hybrid power system

(b) Simulation results

Trip of utility grid



Voltages plot at all load buses

(1) Conclusion

- This thesis proposed and designed a hybrid power system with energy storage on a real power grid with real grid data and loads in Western Libyan grid power system and improve its stability. The power sources of the hybrid power system are PV system, ESS, and generator sets.
- The reactive power has a major role in voltage stability, Q-V curve analysis is important for planning and designing a power system, the controllers in the system could behave incorrectly and cause system to collapse if one bus in the system have negative Q-V sensitivities. The results show that all load buses are stable in the system.
- Designing a hybrid power system at a location is required a complete study of the available renewable energy sources at that location to design a suitable hybrid power system for that location. Libya has a great potential of solar energy and wind energy; these resources are various from cities to another in Libya as Libya has vast area. Wind speed in Bani Walid is not high enough. A design of wind turbines for large power system is not feasible in that area.

6- Conclusion and Future Work

(1) Conclusion

- Optimization results show that the COE is reduced to the lowest value with using battery storage in the system, while using the other power sources without battery storage gives a highest COE.
- With including renewable energy. The net percent worth is $78,960,928 and the simple payback period is 9.02 years. This proves that including renewable energy in the system is feasible. The results also illustrate that the emissions are reduced 29% with using renewable energy in the system.
- The design approach has been scaled for different cases. It can be concluded that load growth and decreasing irradiance rise the COE.
- The PV and battery sizing are affected by the load growth. The irradiance sensitivities of -5%, 0%, 5% does not affect much on battery sizing and it has no effect on battery sizing at diesel price sensitivity of 30%
- The rejection of PV or the utility grid do not have any negative impact on the system since it can be supplied by the other sources in the system.

6- Conclusion and Future Work

- The results show that the generator governor (Woodward UG-8) and the exciter (IEEE Type AC4) of the generator sets was able to recover the stability of the system and PSS1A damped the rotor oscillation quickly
- The performance of OLTC is also presented. The results illustrated that OLTC improved power flow and helped to recover voltage level to close to the nominal value during transient stability.

(2) Future Work

- Controllers in generators can also be designed by using UDM as well as a master controller on the grid for transient stability analysis enhancement in hybrid power systems.
- Other energy storage options like pumped hydro could be studied.
- Other large solar systems, e.g. central receiver system, dish Stirling system and paraboloid
- Reflector based systems could be studied for Libya.
- Economics of gas vs. oil based generators could be studied and compared.
- Effects of dust on PV system, dust cleaning methods can be studied and compared.

Thank you for your kind attention!

Any questions ?