The Impact of High Pentration PV Power on the Libyan Power Network

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***Abstract*—** Renewable Energy Authority of Libya (REAoL) has a strategic ambitious action plan for renewable energy. The plan aims to reduce the dependence on the use of fossil energy sources and increase the renewable energy penetration rate to 20 % from renewable energy by 2035. The aimed plan consists of 5000MW variable renewable energy sources (mainly PV and wind) to be implemented in different sites to meet the national target.

This paper investigates the impact of integrating photovoltaic plants (PVPPs) with high penetration levels during the period 2022-2025 which expected to be about 10% in the year 2025. The impact of high penetration levels of PVPPs on the rotor angle, and power delivered to the network. The study includes whether the system frequency is going to be affected when introducing PV power plants and loss of the largest unit of conventional power at the same time.

Load flow analysis was used to examine the network capacity before and after integrating the desired PVPPs, and to assess the upgrading of the transmission network to increase its capacity. Furthermore, the impact of the output power generated from PVPPs on the steady state voltage was explored during normal conditions.

The behavior of the network generation units was monitored during transient conditions of operation i.e., three-phase short circuit on certain transmission lines and outage of a large generating units, in order to study the impact of high penetration levels of PVPPs on the rotor angel, power delivered to the network and on the frequency stability. NEPLAN smart simulation tool was used for implementation of all simulation studies.

Keywords: PV Power Plants, Load-Flow, Frequency, 3-phase fault, Stability, Libyan Network, Renewable Energy (RE), Point of Common Coupling (PCC).

الملخص:

لدى جهاز الطاقات المتجددة الليبية (REAoL) خطة عمل استراتيجية طموحة للطاقة المتجددة. تهدف الخطة إلى تقليل الاعتماد على استخدام مصادر الطاقة الأحفورية وزيادة معدل تغلغل الطاقة المتجددة إلى 20٪ بحلول عام 2035. وتتألف الخطة المستهدفة من 5000 ميجاوات من مصادر الطاقة المتجددة المتغيرة (بشكل أساسي الكهروضوئية والرياح) ليتم تنفيذها في مواقع مختلفة لتلبية الهدف الوطني.

تبحث هذه الورقة، تأثير دمج المحطات الكهروضوئية بمستويات اختراق عالية خلال الفترة 2022-2025 والتي من المتوقع أن تكون حوالي 10٪ بحلول عام 2025. تأثير مستويات الاختراق العالية للمحطات الكهروضوئية على استقرار زاوية الدوار لمحطات التوليد، والطاقة المرسلة إلى الشبكة الكهربائية. تتضمن الدراسة ما إذا كان تردد الشبكة الكهربائية سيتأثر عند إدخال محطات الطاقة الكهروضوئية وفقدان أكبر وحدة من الطاقة التقليدية في نفس الوقت.

تم استخدام تحليل تدفق الحمل لفحص سعة الشبكة الكهربائية ذات الجهد العالي قبل وبعد دمج محطات الكهروضوئية المطلوبة ، ولتقييم مشاريع ترقية شبكة النقل لزيادة قدرتها. علاوة على ذلك ، تم استكشاف تأثير الطاقة المتولدة من محطات الكهروضوئية على جهد الحالة المستقرة للشبكة الكهربائية أثناء الظروف العادية.

تمت مراقبة سلوك وحدات توليد الشبكة أثناء ظروف التشغيل العابرة ، أي دائرة قصر ثلاثية الطور على خطوط نقل معينة وانقطاع وحدات توليد كبيرة ، من أجل دراسة تأثير مستويات الاختراق العالية للمحطات الكهروضوئية على استقرار زاوية الدوار لمحطات التوليد ، تغير الطاقة المرسلة للشبكة وأيضا على استقرار تردد الشبكة الكهربائية. تم استخدام أداة المحاكاة الذكية NEPLAN لتنفيذ جميع دراسات المحاكاة.

الكلمات المفتاحية - محطات الطاقة الكهروضوئية ، تدفق الحمل ، التردد ، قصر ثلاثي الأطوار ، استقرارية الشبكة ، الشبكة الليبية ، الطاقة المتجددة (RE) ، نقطة التوصيل المشتركة.(PCC)

I. INTRODUCTION

Renewable energy sources are recently becoming one of the most promising topics of energy systems and policies. Most countries around the world have changed their vision toward energy, turning their attention to Renewable Energy (RE) as the world ambition is to accelerate deployment of the green technologies. Among the different renewable sources, Photovoltaic generation plants have reached a fast growth in the decades with capacities ranged from small residential application to large – scale grid connected commercial projects. According to International Energy Agency (IEA) Solar PV accounted for 3.1% of global electricity generation with 821TWh, and it remains the third-largest renewable electricity technology behind hydropower and onshore wind and added total energy from PV may reach to 6970 TWH by 2030 [1].The impact of large-scale PV based generation units on the power networks and the quality of power delivered are the focus of many strategic researches.. Unlike conventional generation units, high-capacity PV units, , will have an impact on the dynamic performance of the power system. Thus introducing large scale PVPs to a power network will have an important impact on the reliable and stable operation of interconnected systems [2,3]. Based on that the assessment of the grid-connected operation characteristics in order to manage the operation of the grid that includes high PV systems is necessary for safe and reliable operation of the grid, incorporating the applicable criteria that follow.

PVPPs creates additional challenges to support the transmission networks stability, not only during normal operation but also in the occurrence of abnormal disturbances [2,3]. These abnormal conditions include different types of faults, to which a bus- bar or a transmission line might be subjected to (three phase to ground fault, single phase to ground fault, phase to phase fault, and etc.), tripping of a main transmission line, outage of large conventional generating stations and heavy change in load. Accordingly, introducing PVPs to any grid will change the operating scenarios. Studies should be conducted to anticipate the most optimizes operation scenarios that maintains the transmission network's stability and the power supply reliability.

In this paper, the impact of integrating photovoltaic plants with high penetration levels into the national Libyan power network was studied in terms of voltage values before and after integrating the desired PVPPs, also the network behavior was explored during the abnormal condition when the PVPPs are connected in 2025 (Three-Phase short circuit between Point of Common Coupling PCC of the PV station and the network and tripping the largest units in the network) taking into consideration the upgrading of the transmission network projects which were taken from General Electrical Company of Libya (GECOL) progress reports.

This paper is organized as following: Section II presents an overview for the power and transmission system in the Libyan network. Section III modelling the predicted network in 2025. In section IV represents the simulation result and discussion. Finally, in section V conclusion.

II. OVERVIEW FOR THE LIBYAN POWER AND TRANSMISSION SYSTEM

The transmission voltage levels for the Libyan power transmission system are: 400/220/132Kv. The sub-transmission voltage level is 66/30kv while the distribution voltage level is 11Kv. The national network covers the whole country from Tunisian border in the west to the Egyptian border in the east, and extended down south to Kufra and Tragen in the southern of the country. The Libyan network is divided to the 7 zones which are:

1. West Zone.
2. Tripoli Zone.
3. Central Zone.
4. Southern Zone.
5. Benghazi Zone.
6. Green Mountain Zone.
7. Srir and Kufra Zone.

A. Libyan Network at 2025

According to the Libyan strategic plan about 1000 MW of PV power suppose be finish and connect to the grid by the end 2025 [4]. However, the network will be reinforced by some projects such as: new power generation, substations and transmissions line. Also, the most importantly the maximum load is expected to reach 10000MW as GECOL referred [4].The tables below are the projects to be considered in 2025. It has been considered the projects that already planned and started according to GECOL plan [5,6,7].

Table. [1] Substation projects to be competed in 2025.

Substation Name	kV	Zone	Progress %
ABU-ARQUIB	400	2	80
BAB - AlZIZIA	400	2	10%
TRIPOLI - SOUTH	400	2	98%
AL-ZERA	400	2	10%
TUBRUK	400	6	86%
BEADA	400	6	72%
UM ARANEB	220/ 66	4	38%

Table. [2] Transmission projects to be competed in 2025.

From	to	Length KM	Progress	kV	Line Type	Zone
Tragen	Um Araneb	40	30%	220	OHTL	4
Rways	Abu Arqoub	200	83%	400	OHTL	Tie line between 1 & 2
Abu Arqoub	Ataba	85	80%	400	OHTL	2
BSMD	Ataba	45	80%	400	OHTL	2
Ataba	Janzour	76	94%	400	OHTL	2
Sdada	BNWLD	98	89%	220	OHTL	3
North Bengahzi	Beada	176	81%	400	OHTL	6
Beada	Tubruk	270	80%	400	OHTL	6
Agdabia	Srir	97%		400	OHTL	Tie line between 5 & 7
Benghazi Power	HDEKA	16.7	60%	220	Cable	5
Homs -Power	Homs - WEST	16	99%	220	Cable	3
BSMD	Al-Zera	45		400	OHTL-cable	2
Al-Zera	Bab - Alzizia	6	0%	400	OHTL-cable	2
Tripoli -south	Bab - Alzizia	10	0%	400	Cable	2
Tripoli -south	Tripoli - west	36	83%	400	Cable	2
Seraj	Alriyadia	7	95%	220	Cable	2
Seraj	2 March	4	98%	220	Cable	2
Alriyadia	Jser Hadidi	10	87%	220	Cable	2
Jser Hadid	General store	5.2	68%	220	Cable	2
Aldawa Islamia	Tripoli South	6	67%	220	Cable	2

Table [3]. Total power generating stations statues in the Libya network at 2025.

Power Plant Name	Number of units	Rating of each unit (MW)	Total Active Capacity
Zawai 220 kV	6	140	840
Zawai 400 kV	3	150	450
Rways 220 kV	4	120	480
Rways 400 kV	2	150	300
Homs Power Plant	2	200	400
	4	150	600
Misurata Steel	3	80	240
Misurata Power	3	230	690
Khalij	2	250	500
Ubari Power Plant	4	150	600
Zwitina	2	200	400
Benghazi 220 kV	2	120	240
Benghazi 400 kV	3	220	660
Srir 220 kV	1	200	220
Srir 400 kV	2	200	400
New Tobruk Power Station	4	170	680
New South Tripoli	5	200	1000
New Units in Misurata Station	3	220	680
Derna Station	1	170	170
Sabha Power Station	2	170	340
New Tripoli west	4	160	640

As the PV plants distributed in several geographic locations in Libya. Table below shows the projects location, rated power and the nearest PCC name

Table [4]. PV projects.

Project Location	Rated Power (MW)	PCC substation	Zone
Jado	100	SHKSHOK	1
Gdamis	200	GDAMIS 400	1
IDAEA	50	AGLAT	1
Bir Dofan	150	Bir Dofan 400	3
TININA	50	BNWLD	3
Tawerga	50	ZAMZAM	3
Hoon	100	HOON	4
Semnu	100	SEMNU	4
Sabha	100	SEBHA- west	4

B. Short Circuit Power Ratio

In the evaluation of the impact of the connection of a new plant to the grid, the short circuit power ratio has been calculated for every connection point. The short circuit power ratio at the PV plant Point of Common Coupling (PCC) is also a parameter to evaluate the capability of the system to integrate the same plant without or with limited issues. A three – phase fault has been applied to the network substations to demonstrate the value of the fault and calculate the short circuit power ratio in the PCC

Table [5]. Short circuit current Values at the 2025 network.

Substation Name	Voltage level	KA	Zone
SHKSHOK	220	13.287	1
AGLAT	220	16.687	1
AGDAMIS	66	11	1
BNWLD	220	10.258	3
SDASA	220	11.178	3
HOMS	400	21.466	3
MSRTA	400	23.87	3
SEMNU	220	7.842	4
HOON	220	4.854	4
SBHA-West	220	8.329	4

The relation between the system strength and the PV plant size is estimated by calculating the Short Circuit Ratio (SCR) index. The SCR index is obtained by dividing the short-circuit MVA at PCC by the plant rated (maximum) real power output. Plants with a low SCR (<3) tend to experience stability problems, [8].

As the PV plants are distributed in several location, mostly in west and south zones. The SCR ration has been calculated for every PCC which are: SHKSKUH, GDAMIS and AGLAT in Zone 1. BNWLD, SDADA, TMINA, HOMS 400 and MSRTA 400 in Zone 3. HOON and SEMNU in Zone 4.

Table [6]. Short Circuit Ratio at PCC.

Substation	PV rating	SCR	Indication
SHKSHUK	100	29.2	Strong Grid
AGLAT	50	73.3	Strong Grid
GDAMIS	200	6.1	Strong Grid
BNWLD	50	45	Strong Grid
SDADA	50	48.8	Strong Grid
Bir – Dofan 400	150	57	Strong Grid
HOON	100	18.13	Strong Grid
SEMNU	100	29.3	Strong Grid
SABHA-WEST	100	31.1	Strong Grid

III. REPRESENTATION OF PV PLANTS

The photovoltaic plants are inserted in the model as single independent bulks of 50 MVA and P.F =0.95 (leading), all connected 30kV or 66kV common busbar depends on the existed substation, then connected to the high voltage grid via step-up transformers. Every 50MVA of PVPP requires two 63MVA transformers to be connected to the grid. With the purpose of assuring the N-1 security condition

The PV plants have been represented in NEPLAN analysis tool by a specific element which is called AC Disperse Generator.

For a first assessment of the impact of the PV plants into the grid, this approach can be acceptable, however it is recommended that, either at bid or at contracting stage, a more details for the models are needed [9].

For the dynamic NREPLAN built-in library has an extensive predefined controller for synchronous machine and Photovoltaic regulators. Also, RMS-DQ0 has been chosen as solution method as the method meet the research aim (Assessment of dynamic security of balanced power grid, Rotor angle response to a transient disturbance, Assessment of dynamic behavior of AC Disperse generators) [10]

A. Assessment Criteria

The PV plants have to be compensated by a power reduction in the existing traditional power plants in order to avoid an excess of generated power when the PV plant is working, for each connected PV project, the power of the remaining stations in the West and south Area has been decreased by disconnecting an equivalent power from the new PVPs as a criterion to compensate the PV power, it has been decided to disconnect the synchronous generators for each zone by the same amount of new PV power in that zone. For example, in zone 1, 350 MW will be decreased equally from the traditional power station in zone1. The same criteria will be applied for Zone 3 and Zone4.

The dynamic transient stability for the Libyan power grid was examined by assessing the behavior of the power generation units and the PVPPs response during the abnormal condition of three phase to ground fault at the tie line between the PVP PCC to the network and loss of generation of large-scale conventional units.

A 3ph short circuit was set into one point of the line between PCC to the network, namely 10% of the line length with reference to the PCC node, so that to trigger the distance protection intervention in Zone 1 [9].

It has been compared the dynamic results before and after the PVPPs at 2025 to find the impact of the PVPP on rotor angle and power delivered to the network. Also, tripping the largest unit in the network which is Khalij station with power rating 250MW and monitor the frequency fluctuation when all PVPPs are connected then the loss of the unit occurred.

Therefore, the fault was applied to the same lines in the different zones before connecting the PVP and monitor the nearest power units for fault location.

The study considered 0.1sec as fault clearing time for the former cases.

IV CASE STUDY RESULTS AND DISCUSSION

A. Load Flow Results

The load flow analysis had been applied to ensure that the network is working in safe in terms of voltage level in 220kV and 400 kV substations and overloading lines, knowing that the acceptable voltage level is ±5%, for emergency condition is ±10% and the maximum loading of the lines is about 100% referred to GECOL criteria. Tables [7] and [8] show the load flow analysis summary before and after PVPPs.

It has been noted that the voltage violation decreased as well as the power loss for the whole network due to new installed PV power near to the load centers zone1 and zone 3, therefore the power that delivered from zone 2 to meet the demand in zone 1 and 3 will decrease then as a result the power loss will decrease as well.

Table [7]. The summary of load flow analysis results of the Libyan grid at 2025 before Connecting PVPPs.

	P-Loss (MW)	Q-Loss (MVAR)	P-Gen (MW)	Q-Gen (MVAR)	P-load (MW)	Q-load (MVAR)
Network	221.878	-2274.757	10169.508	3746.1	9947.63	4401.459
Area 1	221.878	-2274.757	10169.508	3746.1	9947.63	4401.459
Zone 1	31.844	13.613	2070	699.85	1251.29	521.714
Zone 2	45.724	-453.494	1640	779.832	3232.5	1339.001
Zone 3	42.845	-470.728	2733.258	1021.408	1870.72	859.683
Zone 4	39.517	-289.493	960	211.523	911.12	395.495
Zone 5	29.853	-498.375	1300	728.382	1740.7	836.591
Zone 6	18.564	-402.652	866.25	228.696	637.5	309.906
Zone 7	13.532	-173.629	600	76.409	303.8	139.069

Table []. The summary of load flow analysis results of the Libyan grid at 2025 after Connecting PVPPs.

	P-Loss (MW)	Q-Loss (MVAR)	P-Gen (MW)	Q-Gen (MVAR)	P-load (MW)	Q-load (MVAR)
Network	196.552	-2517.228	10144.182	3508.657	9947.63	4401.459
Area 1	196.552	-2517.228	10144.182	3508.657	9947.63	4401.459
ZONE 1	29.208	3.374	2042.5	664.996	1251.29	521.714
Zone 2	45.402	-446.035	1640	803.454	3232.5	1339.001
Zone 3	46.527	-466.509	2753.05	1000.065	1870.72	859.683
Zone 4	15.462	-495.257	945	40.577	911.12	395.495
zone 5	29.576	-507.203	1300	703.043	1740.7	836.591
zone 6	16.866	-431.211	863.632	222.041	637.5	309.906
zone 7	13.512	-174.387	600	74.481	303.8	139.069

Table Below shows some voltage violation in the high voltage substation before and after the PVPPs.

Table [9]. Comparison between the voltage values before and after PVPPs.

	Before PVPPs	After PVPPs	
SUBSTATION NAME	P. U	P. U	ZONE
ZUARA	95	95.3	ZONE1
ATABA	94.6	95	ZONE1
GRIAN	93	93.3	ZONE2
LHIRA	93.85	94.1	ZONE2
ABU-ARQUB	94.4	94.8	ZONE2
TRHUNA	93.51	94.54	ZONE2

B. Stability Result

As illustrated previously, a three-phase short circuit will apply for Zone1,3 and 4 as the PVPPs are integrated in these zones.

B.1 Three Phase Short circuit on the SHAKSHOK – RWAYS line before the PVP in zone 1

A Three – phase fault was applied in 30% distance of Rways – Shakshok line.
Unit 6 in Zawai 220kV power station, Unit 2 in Rways 220 kV power station and Unit 1 in Tripoli south power station were monitored as below figures illustrate.

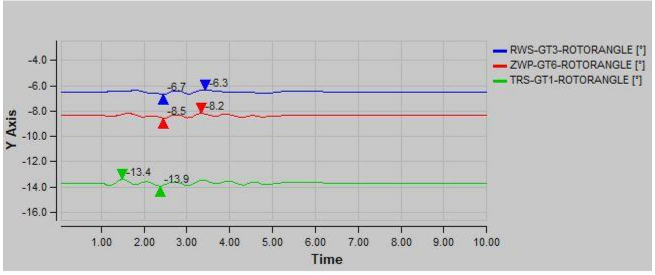

Fig [1]. Rotor Angel at Different Power Plant Units for Zone 1 fault before PVPPs.

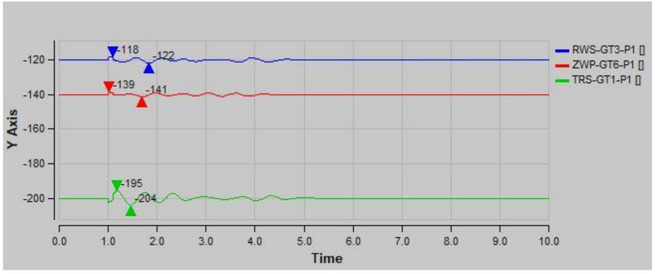

Fig [2]. Power exported to grid by Different Power Plant Units for zone1 fault before PVPPs.

B.2 Three Phase Short circuit on the SHAKSHOK – RWAYS line with presence of PVPPs in zone 1 (Jado PV, Gdamis and Aglat

To compensate the 350MW from PVPPs, it has been disconnecting a three unit in RWAYS 220kV power station The below figures show the variation of the voltage profile for SHAKSHOK and Jado PV nodes, as well as the variation of rotor angle and the power exported to the network for the nearest station's unit in zone 1 (unit 2 of Rways 220kV power station and Unit 6 of Zawai power station 220kV) during the application of a three phase to ground fault for 0.1 s at 10% of distance for Shakshok – Rways line, also behavior of units of Tripoli south was monitored.

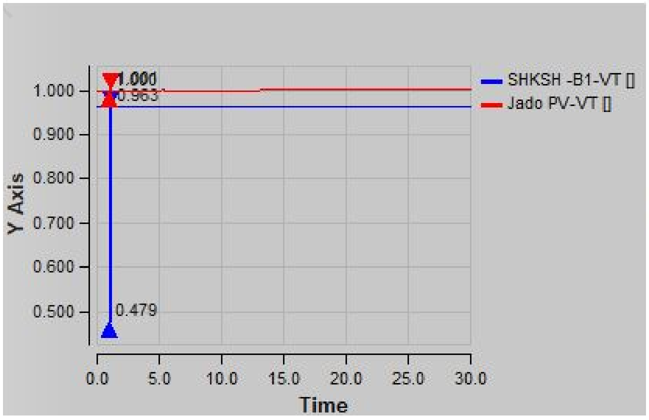

Fig [3]. Voltages at Jado Solar PV Power Plant nodes.

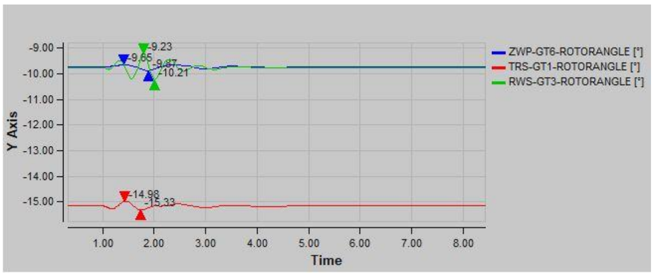

Fig [4]. Rotor Angel at Different Power Plant Units for Zone 1 fault after PVPPs.

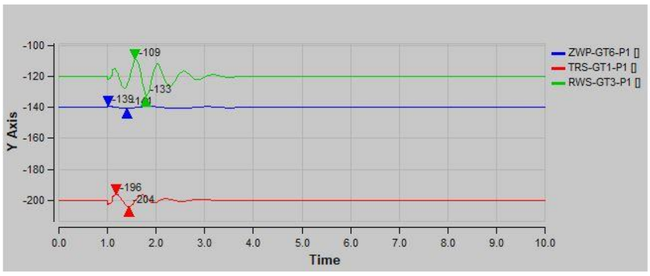

Fig [5]. Power exported to grid by Different Power Plant Units for Zone1 fault after PVPPs.

It has been noted that during the fault at SHAKSHOK – RWAYS line the highest variation accrued in Rways station unit as it's the closest unit from the fault location. However, the rotor angle variation is not critical and within the safe margin and he fluctuation of power exported to grid either from Jado PV power plant and from different units in zone 1,2 and 3 did not extend much time until the system returned to the stability state.

B.3 Three Phase Short circuit on the BNJIM – HOON line before PVPsP in Zone4

A Three – phase fault was applied on BNJIM HOON 220 kV line as its one of the main tie lines that connect zone 4 to zone 3, Also the line was selected to monitor the behavior of zone 4 power station before and after PVP as the line importance lies on connect HOON PV to the network.

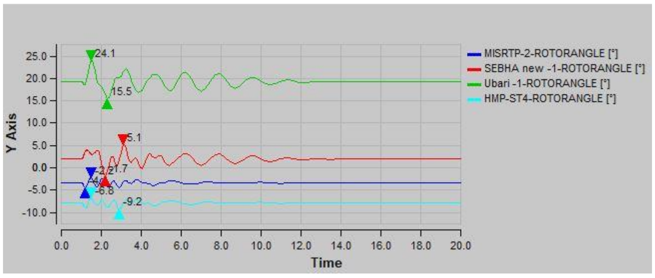

Fig [6]. Rotor Angel at Different Power Plant Units for Zone 4 fault before PVPPs

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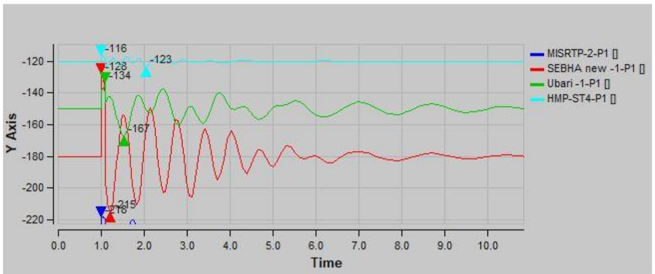

Fig [7]. Power exported to grid by Different Power Plant Units for Zone4 fault before PVPPs.

B.4 Three Phase Short circuit on the BNJIM – HOON line with presence of PVPs (HOON, SEMNU and SEBHA) in Zone 4

Two units in Ubari power station have been disconnected to compensate for the 300 MW from PVP in zone 4. The below figures below show the variation of the voltage profile for HOON PV PCC, as well as the variation of rotor angle and the power exported to the network for the nearest station's unit in zone 4 (unit 1 of Sabha and Ubari power station) during the application of a three phase to ground fault for 0.1 s at 10% of distance for BNJM-HOON transmission line, also the unit's behavior of Misurata and Homs power stations in zone 3 were examined.

It has been noted that during the fault at BNJIM – HOON line, the highest variation of rotor angle accrued in Sabha station unit as it's the closest unit from the fault location. also, the behavior of power stations in zone 3 are normal.

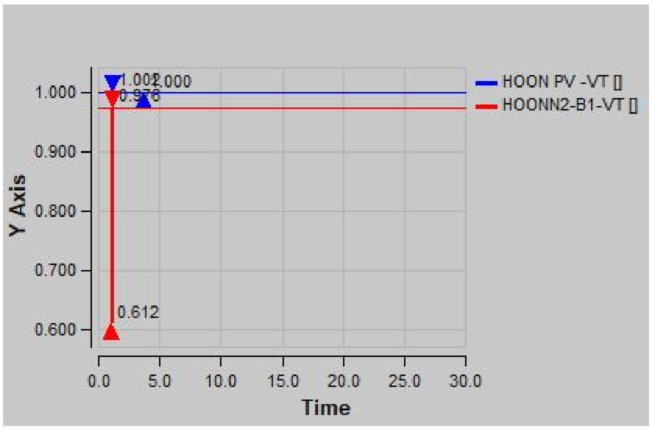

Fig [8]. Voltages at Hoon PV Power Plant nodes.

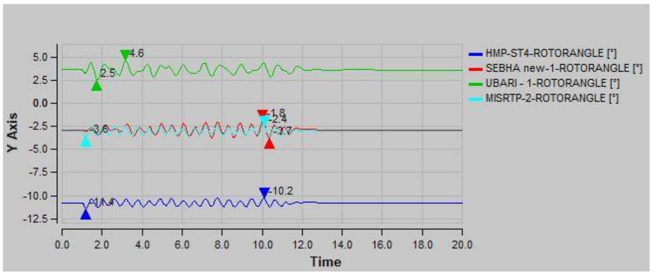

Fig [8]. Rotor Angel at Different Power Plant Units for Zone 4 fault after PVPPs.

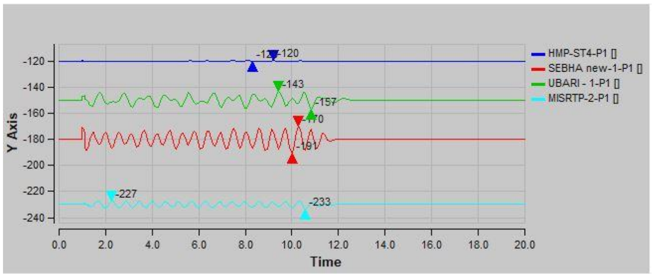

Fig [9]. Power exported to grid by Different Power Plant Units for Zone4 fault after PVPPs.

C. Stabillity resultt when tripping the largest unit

To find the impact of the PVPPs on network frequency, One unit of Khalij power station was tripped as it is the largest unit in the system. This approach was used in many studies globally [11]. Figure below show the frequency variation for the most of the power units in the network.

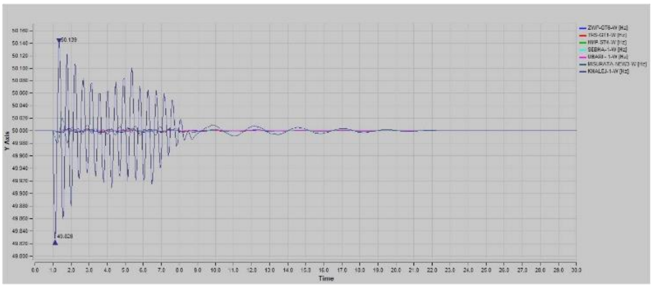

Fig [10]. Frequency variation for the different units when one unit in Khalij power station was tripped.

It has been noted clearly the frequency fluctuation has not exceed the first stage of load shedding which is (49.4Hz) according to the GECOL operational criteria [12,13] which mean when the PVPPs are connected and a trip happened the network's frequency stay stable. One of the main reasons for that is the Libyan network is strong as explained before in the paper and the new PV power is not huge, it's about 10% of the generation power, therefore, its impact would not effect on the network stability.

IV. CONCLUSION

- From short circuit ratio, it is clear that the Libyan network is strong, and it can stand the renewable energy projects such as wind turbines or Photovoltaic power systems and so on. Hence, the high penetration ratio of PV generation could be injected to achieve Libyan renewable energy plan for contributing 950 MW of primary energy.
- Load flow showed that there was low voltage profile in some substation in zone1, 2 and 3 before implementing PV power plants. However, after the PV power were connected and compensate it by disconnect an equivalent power that produced from PV projects from traditional power units from each zone, it has been noted that the voltage profile was enhanced, and overall network loss were decreased.
- Although, disconnecting units to compensate the PV power could not be practical for operation, but these criteria give us a conclusion that even though disconnecting units to compensate the PV power. However, the overall network voltage would not be affected.
- The dynamic stability after applying a three-phase short circuit on the tie line between Point of Common Coupling and the network showed before and after PV power Plants showed that the system is stable in terms of rotor angle variation in addition to the variation of the power that delivered from the different units to the network during the fault.
- Frequency stability has been carried out after outages of Khalij unit. It has been observed that the frequency fluctuation within the permissible range.

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