Using Embedded Renewable Generation to Stabilize Rural Distribution Networks

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***Abstract*— Many developing countries rely on extremely large electricity distribution networks with long distances between substations (e.g. ~100 km on 33 kV distribution). Conventionally electrical distribution networks, are configured with centralized generation supplying via overhead lines (OHL) distributed consumer loads. This configuration can lead to stability problems when supply lines become excessively long, which will result in frequent blackouts, voltage fluctuations and other quality of supply problems (QoS). Generally such QoS problems go hand in hand with increased system losses that must be carried by the utility and ultimately by the consumer. In a recent project in Tanzania, ABO Wind AG demonstrated that such distribution networks, operating at the limit of voltage stability and experiencing significant QoS problems can be stabilized using a combination of technologies such as solar photovoltaic (PV) and battery energy storage systems (BESS). By utilizing optimally positioned substations and incorporating renewable resources with energy storage, the QoS and network efficiency was demonstrated to have improved remarkably.**

I. Introduction

This paper points out the technical impact on grid improvement using PV in the 33 kV distribution network of Tanzanian Electric Supply Company Limited (TANESCO). This also leads to financial benefits caused by reduction of losses. To perform a preliminary network review of the 33 kV supply system the region Mbeya (Tanzania) was chosen as a pilot project. The main feeder is supplied from a 220/33 kV grid substation. The results from this study can be replicated onto other 33 kV feeders in the Tanzania distribution network by applying the network configuration applicable at that specific feeder.

The hypothesis that excessively long rural 33 kV overhead lines are leading to severe voltage instabilities was made by the author. The excessive length of these distribution lines reduces the networks ability to take up additional loads/consumers without detriment to the network voltage stability. This condition can only be corrected by distribution and transmission system upgrades at substantial expense or by means of embedded generation providing a combination of active and reactive power compensation at the load end of the lines.

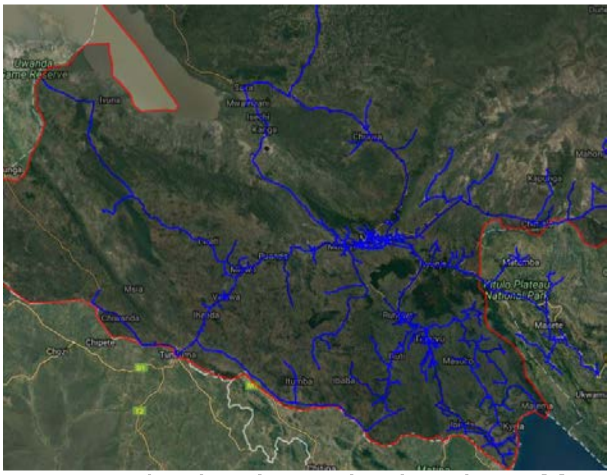

Figure 1: The 33 kV grid connected to Mbeya substation [1]

This study will explore the possibility of using PV generation together with BESS to counter the effect of load swings thereby providing increased load capability, reduced distribution system losses and improved voltage stability. It is well known that reactive power has a 10-fold impact on system voltage, a principle that can be employed with the PV inverters to also provide a voltage-stabilizing source during nighttime conditions.

The field analysis was done in several steps, starting with a pre-study modelling the power grid in *IPSA* using assumed data, to make first analysis of the grid behavior. After this the data collection for detailed modelling in *DIgSILENT Power Factory* based on grid data and locally generated information on-site at the transformer stations was done. The verification of modelling accuracy and voltage sensitivity with measurement were the last step before compiling results for different solar and battery scenarios.

II. Pre-Study in IPSA

A. Model in IPSA

Data available from the *Tanzania Mini Grid Information Portal* provided grid data and substation transformer information. To determine load data on the 33 kV lines and at 33 kV stations the assumption was made that the lines are loaded at the limit of stability. Basically the loads were increased until the static load flow study ceased to converge.

The rural distribution network is extremely complex and not well documented nor branched out. As the primary focus of this study was to understand the effect of a PV park connected near Tunduma, the grid OHL's between Mbeya and Tunduma were modelled by using data overlaid from the *Mini Grid Information Portal*.

The model shown in figure 2 will be used to understand the voltage sensitivity to load changes at the consumer and reactive power control by means of local STATCOM's and reactors.

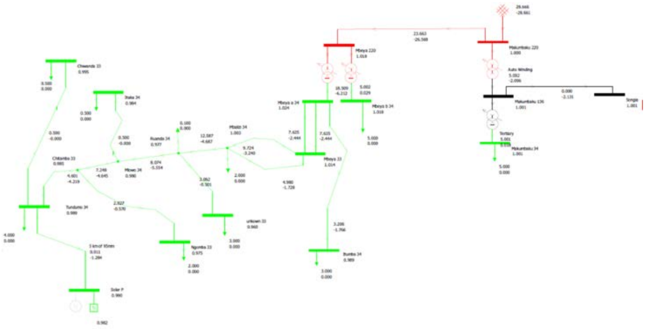

Figure 2: The 33 kV rural grid Mbeya to Tunduma

For the load information on the 33 kV lines and at 33 kV stations the maximum load was applied that can be supplied at the end of these extremely long lines before the static load flow study ceases to converge. At this point, it should be mentioned that for these first simulations several simplifying assumptions had to be made, before progressing to project execution stage. An hourly load profile was assumed based on the data obtained by TANESCO website [2]. The PV park will not be out of service during critical periods.

B. Simulation with IPSA

The simulation in *IPSA* was divided into two basic scenarios comparing the daytime and the nighttime with and without reactive power compensation supported PV system.

Performing a load flow analysis with the assumed loads showed that the voltages on many grid busbars are very quickly reduced to below the 95% level as indicated in the blue boxes of the figure below.

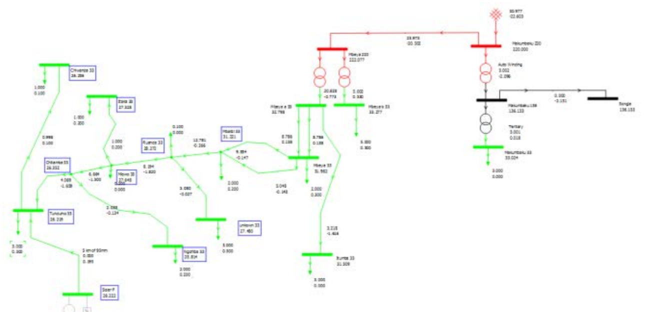

Figure 3: Daytime power grid

The core issue with such a weak grid is how the busbar voltages change when the load reduces to minimum values at night for instance. Another analysis showed how the busbar voltages increased when the load reduces to minimum values for instance at night. Voltages that are too high (above 105 %) are caused by OHL capacitance that is uncompensated by line inductance from loads or by means of compensation equipment. This is shown in figure 4.

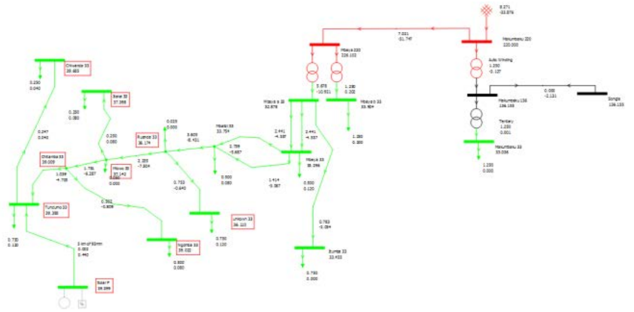

Figure 4: Power grid during night-time

Second aspect of the load flow analysis showed that during daytime the losses are extremely high: round 12 %. During nighttime, the losses rose up to 18 %.

Including a reactive power compensation combined with a PV system to the model leads to a voltage increase and a loss reduction in both scenarios. In the daytime scenario the capability from the PV park supplies current that flows towards substation thereby reducing line loading. This reduces losses in the ratio I^2R – square of current multiplied with the resistance. The losses were reduced to 4 %. By utilizing the reactive power compensation capabilities the OHL capacitive sources are compensated with inductances. This effectively controls the voltages on all busbars in the 33 kV grid. The voltage level at all busbars stayed in limits of 95 % and 105 %.

During nighttime, the reduced load demand did not need support by an additional generation system. The reactive power compensation of the system also influenced voltage level and grid losses. The losses were reduced to 6%.

Using an assumed grid model it could be shown that the network due to extended lengths of OHL is extremely sensitive to load variations. The *IPSA* model was used to demonstrate that these sensitivities could be partially mitigated by managing the overhead line loading and by controlling reactive power during periods of low loads. [3]

The next step is to determine how suitably sized PV and energy storage can create space to promote increased consumer capacity thereby contributing to the development of the Tanzanian economy.

III. Simulation with DIgSILENT PowerFactory

The purpose of the second analysis was to accurately determine the benefits from providing active power in the daytime and using battery storage to make active power available during peak period in the evening and the voltage regulating capability from additional reactive power. To improve the level of confidence in the calculations accurate load data was required. Unfortunately, the only load data available was metered at the substations so that the loads at the end of the OHL and at other communities had to be rationed back to these stations.

Network data was collected with help from a local partner. A field trip round Mbeya provided locational information on a large number of distribution transformers plus all feeders including the spur-lines and a detailed model could be generated.

A detailed final model of the part from Mbeya towards the end of OHL including all interconnected feeders and spur lines were built in the simulation program *DIgSILENT Power Factory*, which was also used to perform all simulations in this study. [4] [5]

A. Model in DIgSILENT PowerFactory

Mbeya substation is fed off the TANESCO 220 kV grid which connects from Makambako substation. There are two transformers at Mbeya substation with the apparent power of 60 MVA and 90 MVA stepping from 220 kV to 33 kV. Mbeya substation is the start of eight feeders. Four of the feeders supply Mbeya town and local industry. The connection between Mbeya and Iyunga is made via two interconnectors without the use of any distribution transformers.

At Iyunga substation two 15 MVA transformers connect four new feeders for town and industry around Iyunga. The voltage level of these feeders is 11 kV.

Additionally, at the 33 kV busbar two new feeders start. First one supplies a local cement factory and some small consumers surrounding the area. Main interest of the study was spent on the second feeder called Mbozi feeder.

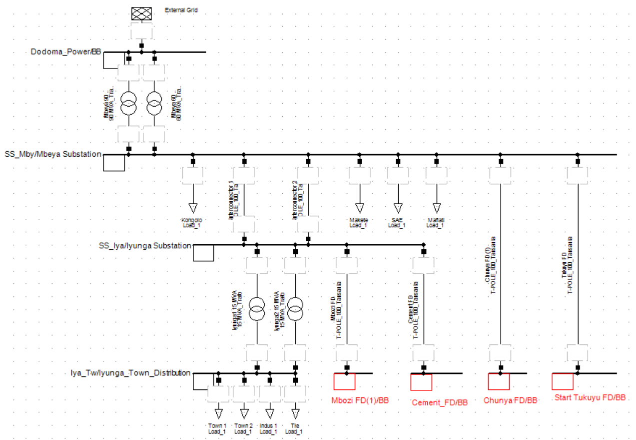

Figure 5: Power supply Mbeya and Iyunga substation

The distribution network comprises two different wooden pole types with 100 mm² ACSR conductors. At distribution points, H-poles with mostly underline transformers connect the consumers to the grid. T-poles increase the distance of the network.

A network model of at least 1000 km of overhead lines and 300 transformers was created. The first step was to analyze the influence of all the transformers on the grid versus the distributed capacitance provided by the conductors. [1] [4] [6] [7]

Principally, every long OHL have capacitive, inductive and resistive components that influence the parameters at the end of the line. The longer the line the greater the sensitivity to changes in load current transmitted through the line. At nighttime, when the loads are low the capacitive effects dominate pushing voltages up, but during daytime, when the loads are high, the resistive and inductive elements of the line dominate - forcing the voltage to collapse. The magnetizing inductances of distribution transformers limit this effect and therefore these magnetizing inductances had to be included in the modelling of the distribution transformers. Moreover different loadings of the lines at different times influence voltage level along the overhead lines. During weak or no-load phases the voltage level rises. The real influence of this behavior cannot be seen in substations because of the automatically controlled tap changer of the power transformers keeping the substation voltage stable. [8]

However, when loads increase, especially considering the high number of distribution transformers along the lines, the voltage level at the end of the line collapses so that not even a filament lamp can function properly. Even worse, devices such as fridges, TV and other fixed load devices, like small industries machines, which are much encouraged in rural areas, will burn out. This poor perception of supply unreliability will prevent further consumers from connecting.

B. Simulation information

The analysis study with *DIgSILENT Power Factory* was based on load profiles from June 2016 to May 2017 collected at Mbeya and Iyunga Substation. The analysis of the grid is divided into parts. In the first part, the real grid behavior is analyzed. For the second part, a solar PV park with its generated power is connected to the grid.

To create this park another Simulation is made. Therefore, sun radiation and a potential connection point near Tunduma are supposed.

After the simulation the BESS was calculated followed by the implementation of the control unit for PV and battery storage with reactive power compensation.

As the result, a grid stabilization system based on a PV park with BESS and control unit for reactive power compensation and night switch off is developed. [9]

Grid stabilization is made with a 5 MWp PV park and a 6 MWh battery which supplies additional 2 MW power to the grid from 19:00 to 21:00 pm.

C. Simulation results

As shown in figure 6, the voltage level for the grid without an embedded power generation source (PV and battery) drops by over 20 %. With one PV-system the voltage drops during day add up to 5 %. During night and due to the switched off PV-storage system the drops oscillate around 10 %.

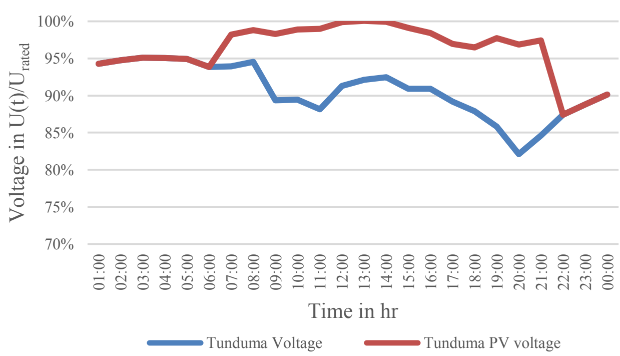

Figure 6: Voltage level Tunduma city

Second aspect, the grid losses are shown in figure 7. The blue line represent the grid losses for one day without a PV-system. The red line stands for the influence of the grid stabilization system to the losses. As recognizable with the feed in of the PV-system during day and the storage system in the evening, a reduction of the losses is simulated. With the grid stabilization system's switch off the positive influence of the power grid will be used. Because the sun is used as a source of energy, the generation of power is low in the mornings and in the evenings. In these periods, losses are increasing. These losses are induced because of the reactive power compensation functionality of the PV-system.

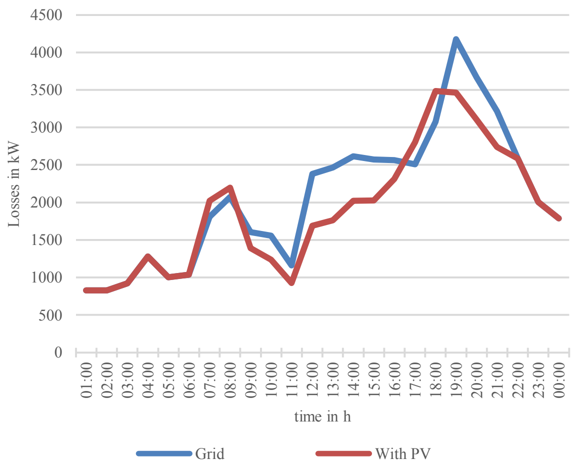

Figure 7: Reduction of grid losses

The influence of grid stabilization with a PV-system and reactive power compensation but without a BESS is shown in figure 8. The graphic is just an example and can be transferred to any other day.

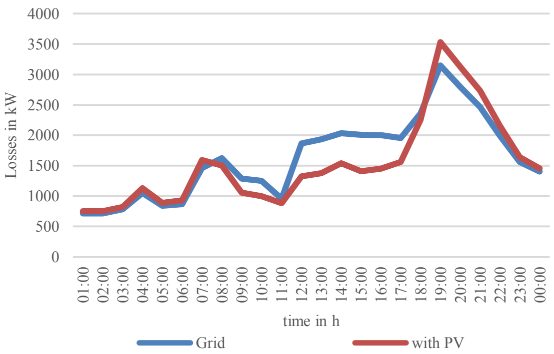

Figure 8: Grid Losses without control unit

Obviously, here is no real solar power generation during the night, but the reactive capability of the PV is maintained as a reactive power compensation function. This influences the busbar voltages during the night load profile. To switch off the grid stabilization during night is necessary because of expanding losses caused by the reactive power compensation.

IV. Possible Future Handeling

There are multiple future handling options for the grid stabilization system. The first possibility is to add another load cycle to the system to compensate the peak load demand in the morning hours. For this during the off-peak period from 22:00 pm until 06:00 am the BESS recharges at a rate of 0.6 MW to prepare for the next generation cycle which lasts from 06:00 am till sunrise at 07:00 am.

In figure 9, the influence of a repeating daily load cycle is shown. The blue line is a characteristic daily load profile of Tunduma. The two load-peaks are before and after work when household appliances increase demand. There is a notably low level of industrial demand during the day shown by the midday dip in consumption. The orange graph shows the net load after deducting the contribution from the 5 MWp PV, which is shown in yellow, from the daily consumption in blue. The battery charging/discharging rate is shown in grey. The charge-level of the 6 MWh battery is shown in red.

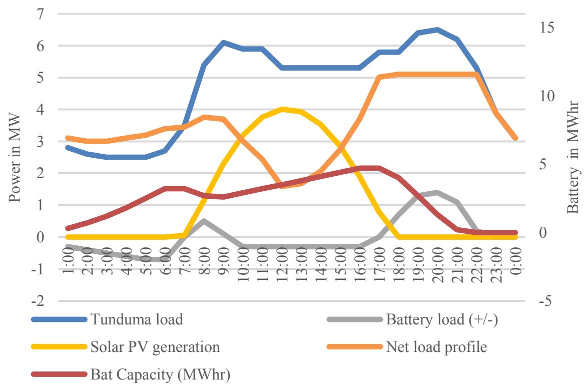

Figure 9: Daily load profile with embedded generation and storage

Figure 10 shows that the PV-system has the ability to reduce the net loading of the overhead line from Mbeya. However as household loads in the early morning and late day are significantly higher, battery storage capacity is required to transfer the energy from midday to the peak load periods.

As the simulations show, a positive impact of grid stability can be realized with one PV-Battery- system. With additional systems at other grid locations there is a potential superior impact on the national grid. In figure 10 the grid is extended with three additional grid stabilization systems. Each system has a 5 MWp PV generator with a 6 MWh BESS and a reactive power compensation functionality.

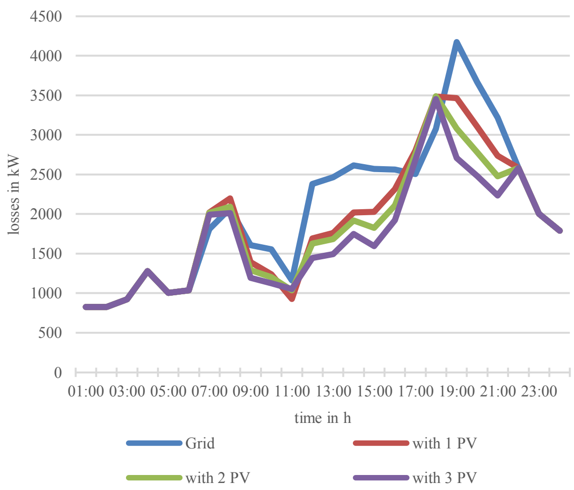

Figure 10: Grid extension with additional grid stabilization systems

By controlling the effective loading of the 33 kV OHL feeding Tunduma using a 5 MWp PV and a 6 MWh BESS grid losses can be reduced. Such a control system improves grid stability.

The results are the stabilization of the voltage level not only at the connection point but also at far away bus bars on the same feeder emanating from Iyunga, and a reduction of losses in this entire part of the power grid.

The simulation shows that each grid stabilization system reduces the losses. Because of the different connection points, each feeder and its spurlines take a benefit of the reactive power compensation functionality and the associated increase of the voltage level.

Although this analysis was performed with a 5 MW PV plant and a 6 MWh battery there is no reason why this cannot be implemented in units of 1 MW Solar and 1.5 MWh battery storage. Obviously the benefits would be additive depending on the number of generating units installed.

V. Conclusion

ABO WIND AG has analyzed a portion of the power grid in Tanzania and developed a solution to stabilize the power grid network using renewable generation. The simulations showed that with using embedded renewable energy generation together with a BESS the 33 kV power grids can be stabilized and grid efficiency improved.

The greater benefits realizable from such investments reside in increased grid capacity which supports additional consumers as well as reduction of losses. Ultimately, consumers won't connect if poor quality of supply damages fridges and air-conditioners. On the other hand, an increased consumer base will support further transmission grid expansions and other small industries machines, and hence discouraging the whole idea of industrialized economy efforts done by the current government in Tanzania.

Thereafter as consumption increases further embedded generation should be added until the consumer base has increased to a point at which it makes sense to add another grid supply point substation connected to the 220 kV transmission system. The concept can be easily scaled in case of higher demand of grid capacity. This brings technical and economic flexibility into electrification of large area countries.

References

[1] Workinggroup of Ministry of Energy and Minerals (MEM), Rural Energy Agency (REA), Energy and Water Utilities Regulatory Authority (EWURA), National Environment Management Council (NEMC), Tanzania Renewable Energy Association (TAREA), Tanzania Bureau of Standards (TBS) and Tanzania Electric Supply Company Limited (TANESCO): Mini-Grids Information Portal. http://minigrids.go.tz/, (01.05.2017)

[2] Tanzania Electric Supply Company Limited (TANESCO):official website. http://www.tanesco.co.tz/index.php, (01.05.2017)

[3] ESMAP – The World Bank: Tanzania – Power Loss Reduction StudyVolume 1: Transmission and Distribution System – Technical Loss Reductionand Network Development. 01.06.1998 https://www.esmap.org/publications?title=&name=&created=&created_1=&field_publication_year_value=&field_publication_year_value_1=&country[230]=230&sort_by=field_publication_year_value&sort_order=DESC&0=230&page=1

[4] Tsakhara, Patrice: Presentation on the Tanzanian solar PV-Hybrid WorkshopHeld in Berlin, Germany. TANESCO, 16.03.2015 https://www.giz.de/fachexpertise/downloads/2015-tanesco-presentation-tansania.pdf

[5] Ministry of Energy and Minerals: The executive sum-mary of power system master plan 2012 update. Mai 2013 http://www.tanesco.co.tz/index.php/investments/investmentreport/23-the-executive-summary-of-power-system-master-plan-2012-updad

[6] Energy and Water utilities regulatory authority (EWURA): The Tanzanian Grid Code: The network Code. 28.01.2014 http://www.ewura.go.tz/?page_id=2122

[7] Sospeter M. Muhongo: Electricity Supply Industry Reform Strategy and Roadmap 2014 – 2025. 30.06.2014 http://www.gst.go.tz/images/TANZANIA%20ELECTRICITY%20SUPPLY%20INDUSTRY%20REFORM%20STRATEGY%20&%20ROADMAP.pdf

[8] Schellong, Wolfgang: Analyse und Optimierung von Energieverbundsystemen.Köln: Springer Verlag Berlin Heidelberg, 2016. - ISBN: 978-3-662-49463-9

[9] Watter, Holger: Regenerative Energiesysteme: Grundlagen, Systemtechnik und Analyse ausgeführter Beispiele nachhaltiger Energiesysteme. 4.Auflage Flensburg: Springer Fachmedien Wiesbaden, 2015. - ISBN 978-3-658-09637-3