Design and Implementation of Smart Grid-connected PV system

DESIGN AND IMPLEMENTATION

Solarex Powering Africa Project

Table of Contents

1.0 Introduction:

Renewable energy sources are the most effective solution to reduce the carbon and hazardous gases in the environment. One of them is Grid-connected PV system, the system have dual purpose two way energy flow and metering of the energy is an important part of the

measurement. The main source of the energy is solar energy, which is being converted by the solar cells, because the energy retrieved from the solar cells is DC so we need a good quality inverter to convert the energy to AC. Then the AC is fed into the home appliances and the extra energy is released to Grid. If due to some problem system is shut down then the energy can be retrieved from the Grid and the calculation of the energy is done by the smart energy meter, which plays an important role. Smart meter measures the difference of incoming and outgoing and then decided that user have to receive or pay the bill.

To investigate the problems such as protection, stability etc the modelling and simulation is performed in the DigSilent power factory and analysis is performed using the tools provided by the power factory. The smart energy meter with block chain technology in embedded to measure the energy flow with various options to pay the calculated bill. The topology for the Grid-connected PV system is given as below

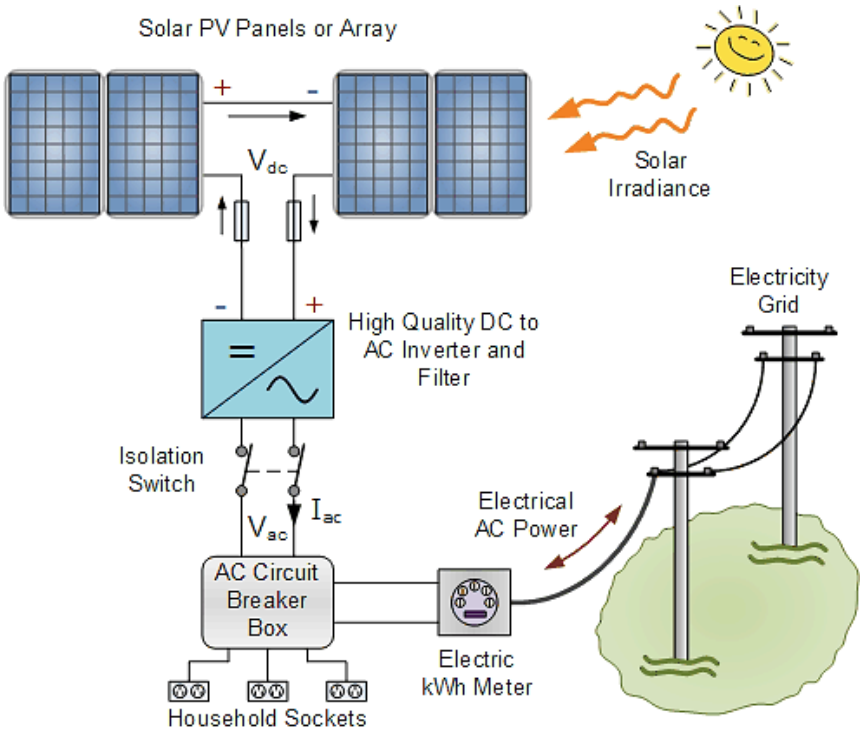


Fig.1 The concept of the Grid-connected PV system

1.1 Features:

The main feature of the lantern are given below

- The system have dual purpose mode; smart energy meter.
- The lantern is atomically triggered based on fuses and circuit breakers.

- The system is low cost and renewable energy source to produce green globalization.
- The system have high quality inverter to convert the DC to AC.
- The system is renewable energy based as powered by solar energy.

1.2 Components:

The components of the system play an important part for the functionality of the system. The designed system is proposed using the low cost solution. To achieve the highest efficiency and compact size of the system, there are CHSM6610P-230, CHSM6610P-235 and CHSM6610P-240 three types of PV module used in the selected station's PV array. The components are their features are given below

- Solar PV Array.

  The solar array id designed using the combination of the solar cells. The solar cells are connected in series and parallel based on the voltage and current requirement of the system.
- Inverter
- Inverter is an important part, which converter the produced DC into the AC. The main issue is that we can't get the exact sinusoidal from the inverter. There are harmonics in the output. To reduce these harmonics we have multilevel approach based on the design and requirement.
- Filter

  The filter circuit is used to remove the ripples and harmonics from the output of the inverter.
- Smart energy Meter

  This energy meter is called smart because it records the bidirectional energy measurements and create the difference of incoming and outgoing.
- Grid

  This is the public Grid, the energy is drawn in case of the solar is not produced and extra energy is fed to the Grid.

2.0 Single Line Diagram:

The step by step description of the single line diagram is given as

- The single line contains the circuit representation of the Grid-connected PV system.

- The components are connected from the elements given on the right side of the DigSilent power factory.
- To create the single line diagram from the top menu we have selected insert option and then we have selected the single line diagram.
- There are three transformers to step up and step down based on the specification.
- The PV array is modelled as a constant current source in the circuit.
- Inverter is used to convert the DC into AC.
- The following figure shows the procedure to create the single line diagram in the DigSilent power factory.

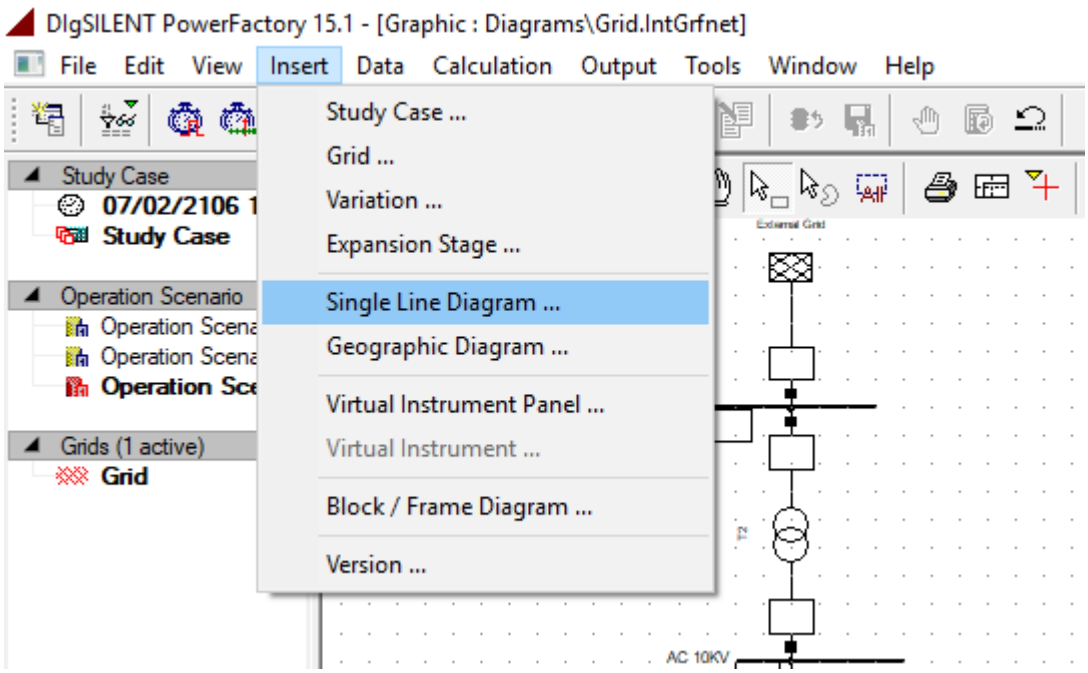


Fig.2 Single Line Diagram Insert Option

Next we have create the Single line diagram as proposed in the paper. In the paper the single line diagram in not shown as a clear picture and having some hidden elements and only represents the main circuit.

The following figure shown the modelled single line diagram in the Digsilent Power factory.

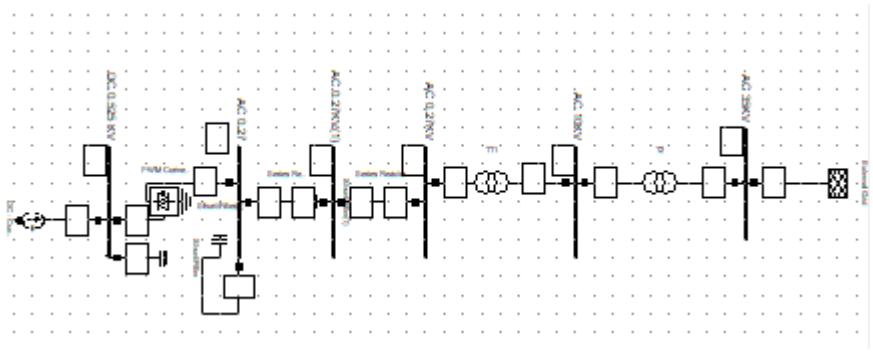


Fig.3 & 4 Complete Single Line Diagram on the Grid-connected PV System

3.0 PV Modelling:

PV modules are designed with the combination of the solar cells. Inside the cells are connected in series or parallel to meet the design requirement. The basic structure resembles to the modelling of the simple diode. The basic equation are implemented in the block/frame diagram to model the PV array.

The equivalent circuit of the solar cell is given below

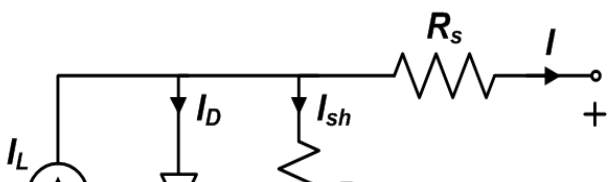


Fig. 5 Modelling of the solar cell

The current equations for the PV are given as below

$$I = I_{ph} - I_o exp^{(\frac{v+IRs}{Vt})}$$

$$I_{o=} \frac{I_{sct}}{\exp(\frac{Voct}{Vt})}$$

Similarly the equation for the output voltage is given as

$$V_{oc} = V_{oct}(\frac{lnE}{lnE_{stc}})$$

To create the PV array model in the DigSilent power factory we have selected the insert option as shown below.

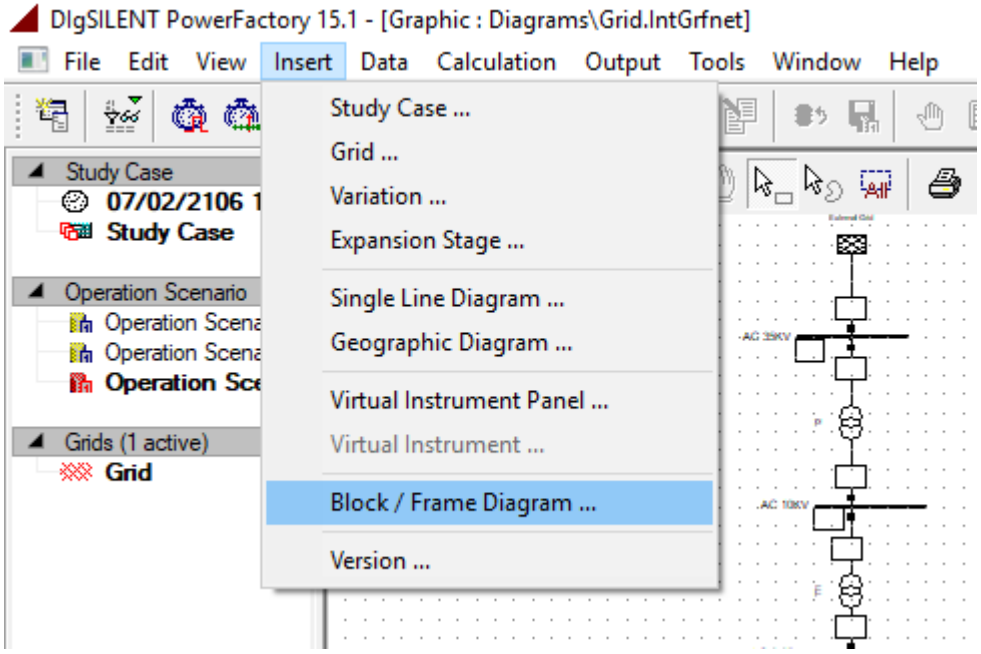


Fig. 6 Insertion of Block/Frame Diagram

Block/ Frame diagram provides the platform for the DSL (DigSilent Simulation Language) and electrical specification of CHSM6610P-235 modules is chosen for the modelling.

The modelling of the PV is given as

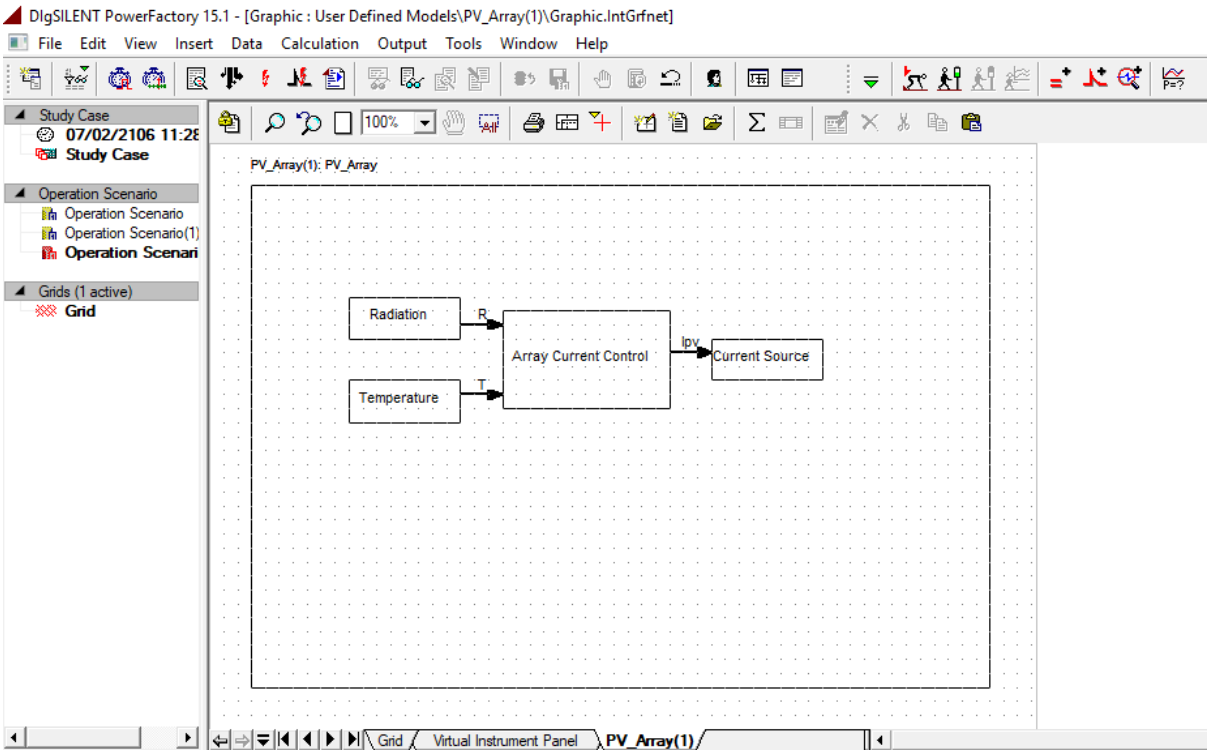


Fig. 7 Modelling of the PV Array

4.0 Modelling of Inverter:

Inverter is an elementary part in the modelling of the Grid-connected PV system as it converts the DC to AC for the use of the appliances. The inverter consists on the three full bridge MOSFET's and the output signal is based on the switching of these MOSFET's so the control strategy for these MOSTEF's is an important part of the inverter. The topology of the inverter is given below

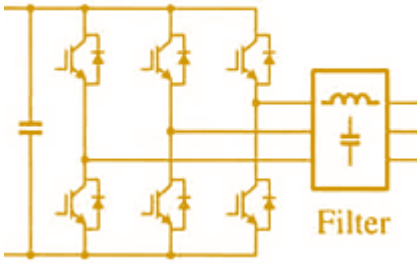


Fig. 8 Topology of the Solar Inverter

To get the high quality sinusoidal signal with lowest percentage of harmonics, multilevel inverter is recommended. As we increase the number of levels then the control strategy becomes complex. Idc is the input of the inverter, Idc is generated by PV and the filtered sinusoidal in the output of the inverter. The Modelling of the inverter is implemented in the frame/block diagram using DigSilent power factory.

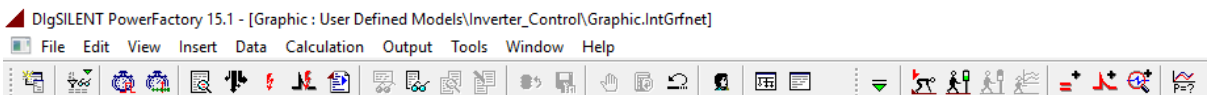


Fig. 9 Inverter Control Algorithm Modelling in DigSilent Power Factory

The switching state of the MOSFET's in the three-phase inverter is shown below

S_{11}	S_{12}	S_{31}	V_{ab}	V_{bc}	V_{ca}
0	0	0	0	0	0
0	0	1	0	$-V_{DC}$	V_{DC}
0	1	0	$-V_{DC}$	V_{DC}	0
0	1	1	$-V_{DC}$	0	$-V_{DC}$
1	0	0	V_{DC}	0	$-V_{DC}$
1	0	1	V_{DC}	$-V_{DC}$	0
1	1	0	0	V_{DC}	$-V_{DC}$
1	1	1	0	0	0

Fig.10 Switching State table for the Inverter control

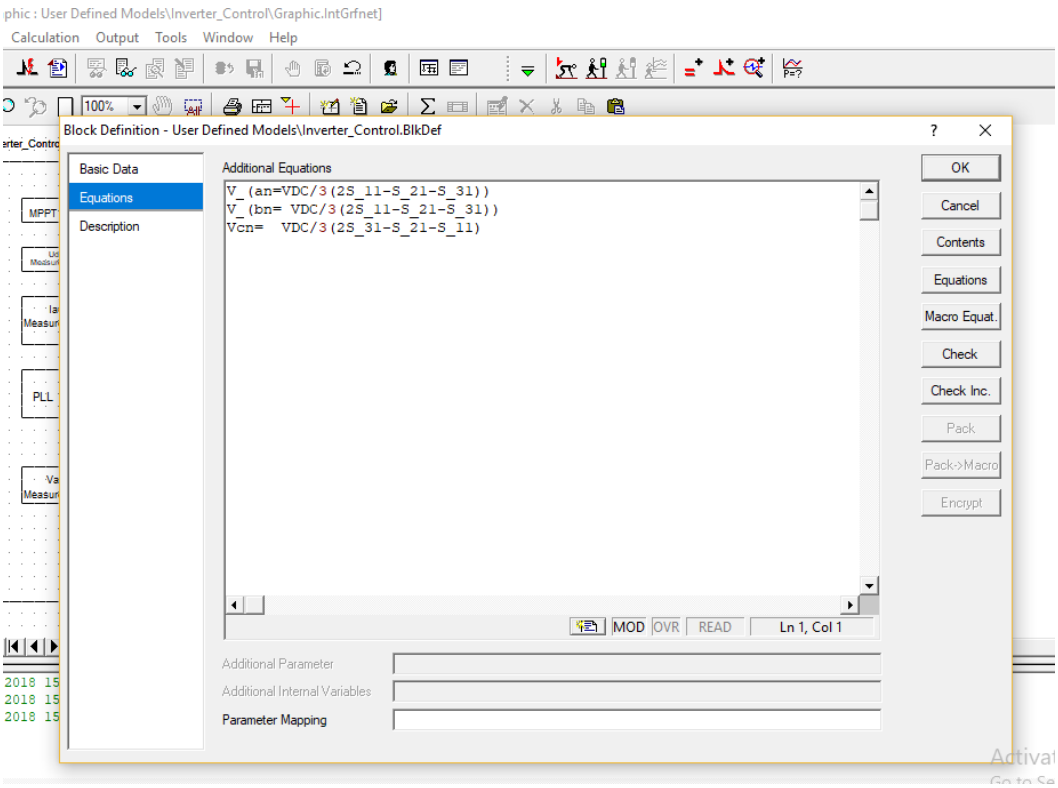
The modelled equations for the control of the three phase inverter are given below

$$V_{an}=\frac{VDC}{3}(2S_{11}-S_{21}-S_{31})$$

$$V_{bn}=\frac{VDC}{3}(2S_{11}-S_{21}-S_{31})$$

$$Vcn = \frac{VDC}{3}(2S_{31} - S_{21} - S_{11})$$

The equations are implemented as given below



5.0 MPPT Algorithm:

The MPPT is basically the algorithm that optimizes the maximum power output and integrates the battery of Grid connected system. This includes the implementation of the algorithm to extract the maximum from the PV. With the change in the radiation, solar intensity and temperature the power in the PV varies with time so the MPPT algorithm is implemented to cover this problem. In this implementation perturbation and observation method is implemented in the frame/ block diagram using DigSilent power factory.

The implementation of the MPPT algorithm in the DigSilent is show as below.

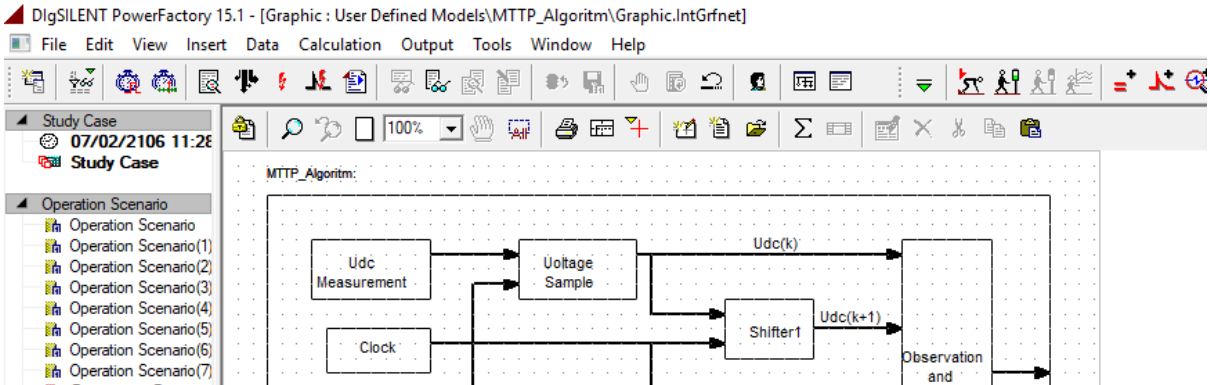


Fig. 12 Modelling of the MPPT algorithm DigSilent power factory

The current samples and voltage samples are calculated on the base of the current and voltage measurement from the PV. The next state in the model is calculated by the shifter1 and shifter 2 and similarly the observation and measurement is responsible to extract the maximum energy from the PV.

6.0 Voltage and Current Control Loop:

The voltage and current control loop are fundamental components of the inverter algorithm. As variation of the load causes the variation in the current and over current can drain the voltage. To handle these all situations the voltage current loop and current control loop works simultaneously and produces the required power at the output. These are called the two loop algorithm. Voltage loop controller have basically PI controller to regulate the voltage for the output. Integrator output is compared with the reference voltage and then the output is fed to the outer voltage loop which adjusts the required voltage.

The implementation of the voltage control loop in the DigSilent power factory is given below.

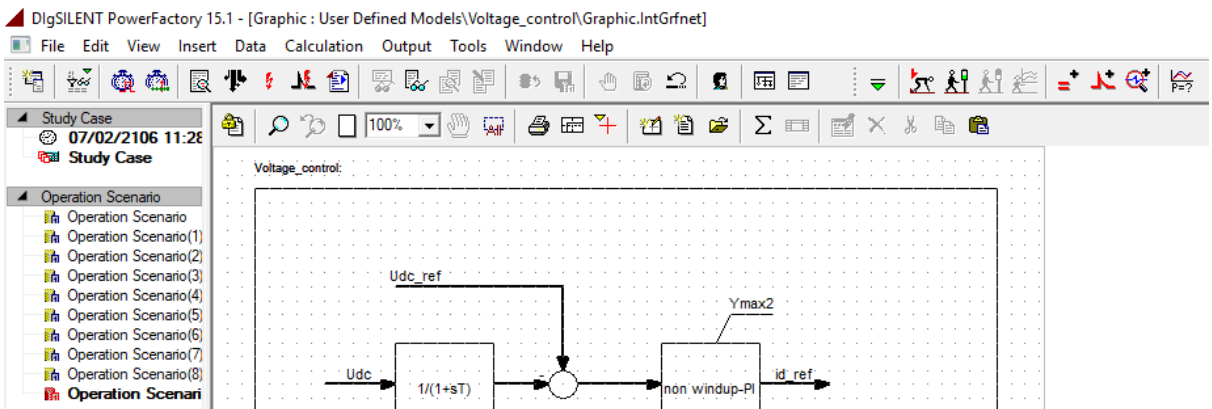
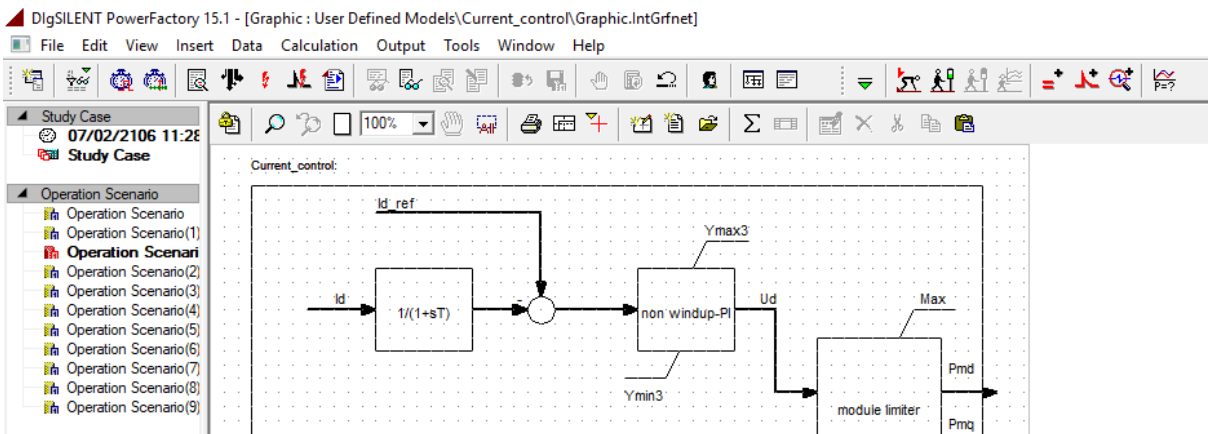


Fig. 13 Modelling of the Current control loop in the DigSilent power factory

The current control loop contains on the two inverter components; one is d and other is q. These two signals are feed to parallel integrator and then limited as the modulation, which gives the output signals.

The modelling of the current control loop in the DigSilent power factory is given below.



7.0 Protection Algorithm:

The protection algorithm controls the both current and voltage and prevents the over voltage and current at the output of the inverter. The implementation of the protection algorithm is based on the limiter circuit. Which limits the output of the inverter. If the current or the voltage at the output increases from a certain limit as defined 1.5In then it automatically shut downs.

The implementation of the protection algorithm in the DigSilent power factory is given below

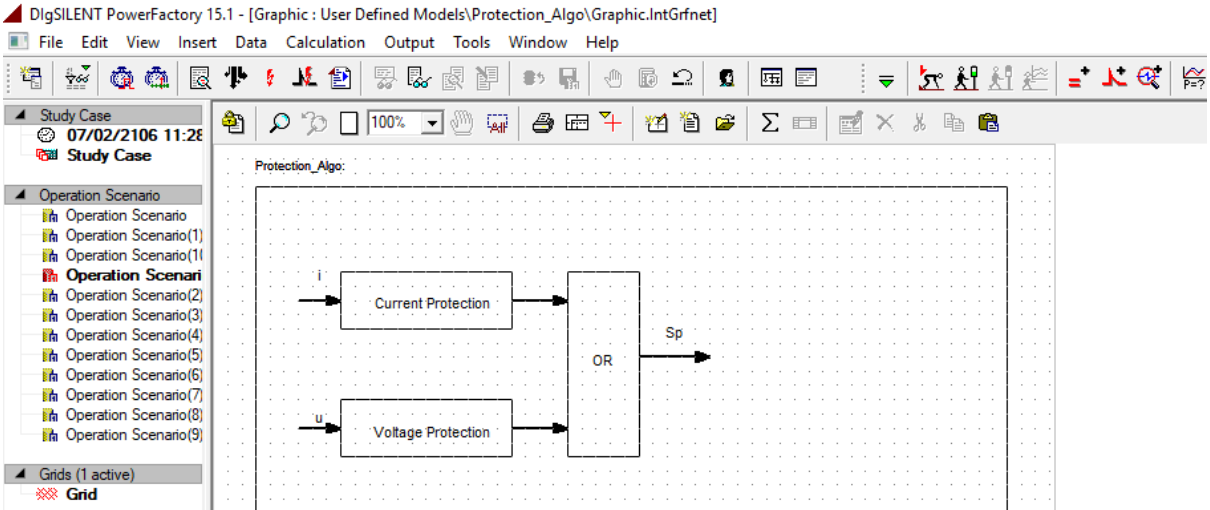


Fig. 15 Modelling of the protection algorithm in the DigSilent power factory

8.0 PV Solar Modules:

PV solar modules are basic components to extract the enegy from the sun and then convert it into electrical energy. The PV solar modules have two types of the implementation which are given below.

PV Solar Park:

The solar PV modules are constructed with the solar cells. This consists the installation of the PV solar modules into open land. This needs to connect more than one PV modules connected in series and parallel according to circuitry. 1 acre is equivalent to 4046.86 square meters, and you can install roughly 150 watts of capacity per m2. Therefore:

- Possible PV system capacity = 4046.86 m2 x 150W/m2 = 607,029 W

We can install slightly over 600 kW of capacity in one acre of land. According to the estimation of an African's house consumes a 5,000 W in an hour. In 24 hours a house will consume 120,000 W. So one acre farm can continuously feed 5 houses for 24 hours.

Rooftop PV Modules:

This is an efficient way to use the natural resources as the energy can be collected from the rooftop of the houses. Mostly rooftops are curved and the maximum average capacity to install less than 20 panels. But this needs separate smart energy meter for every house, which will measure the bidirectional energy flow. The rooftop topology is given below.

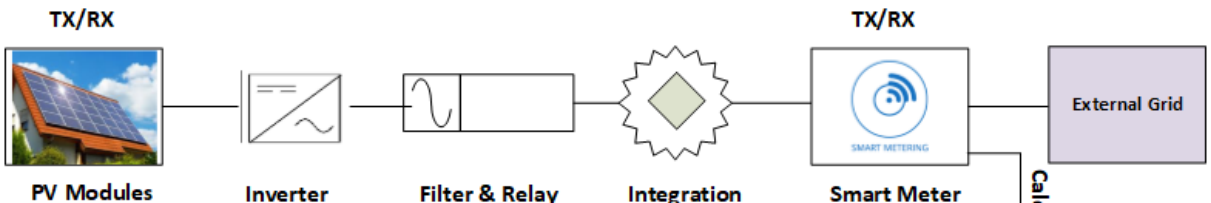
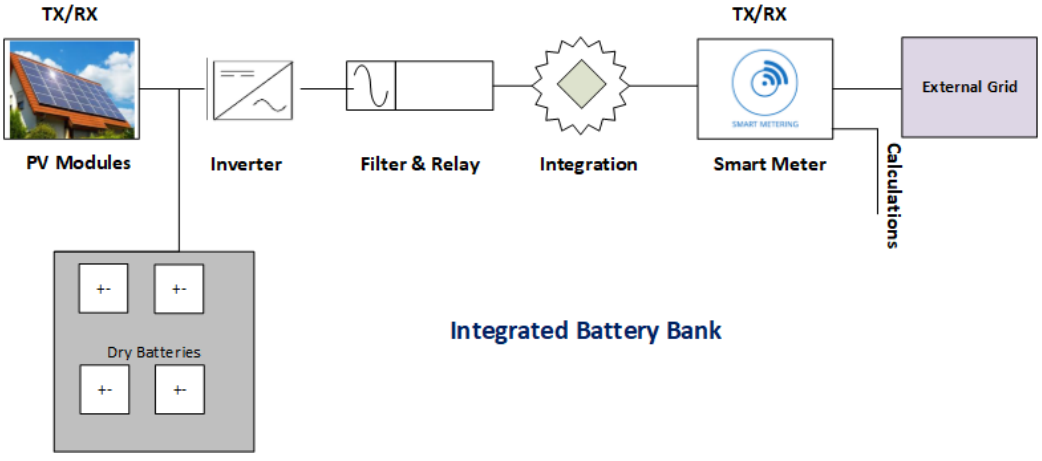


Fig. 16 Roof top based PV installation topology

9.0 Battery Storage:

In our designed model we need to integrate the batteries to store the energy for the rest of the 12 hours in a day. The average sunshine is 12 hours and to use energy we need battery banks to store the rest of the energy in the day time. Many different types of organizations are developing and manufacturing solar battery products, from automotive companies to tech start-ups. While a major automotive company entering the energy storage market likely has a longer history of product manufacturing, they may not offer the most revolutionary technology. So we prefer to use the Lithium ion batteries for the battery bank. On average the voltage rating of the panel is between the 16 and 17 v so we prefer to use the 16V rating of the lipo batteries.

The following figure shows the integrated battery bank for the storage of the DC energy extracted from PV modules.



10.0 Smart Energy Meter:

We need to integrate the smart energy meter especially to the rooftop consumers. The smart meter measures the bidirectional flow of the energy from PV to grid and vice versa. The advanced meter that can send reading digitally with more accurate results to energy suppliers. With the help of smart meters one can easily understand the usage of energy. The meter takes the difference of the incomings and outgoings, if the difference is positive then Supplier Company will pay to the consumer and vice versa. This means households will no longer rely on estimated energy bills or have to provide their own regular readings. Smart meters will also come with an in-home display. This display gives the household real-time usage info, including kWh use and cost. The complete picture of the system is shown below with the extended version of the smart meter.

i

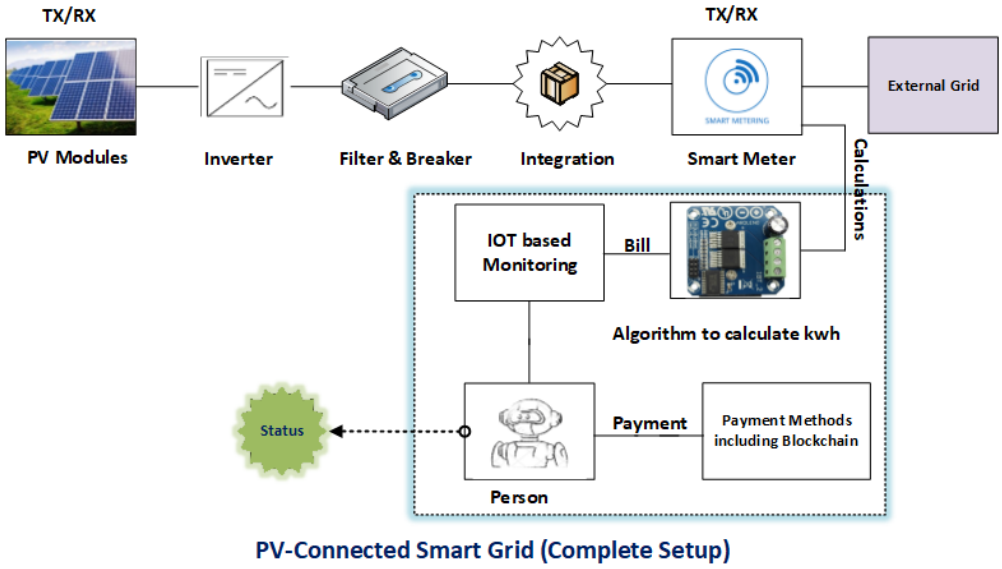


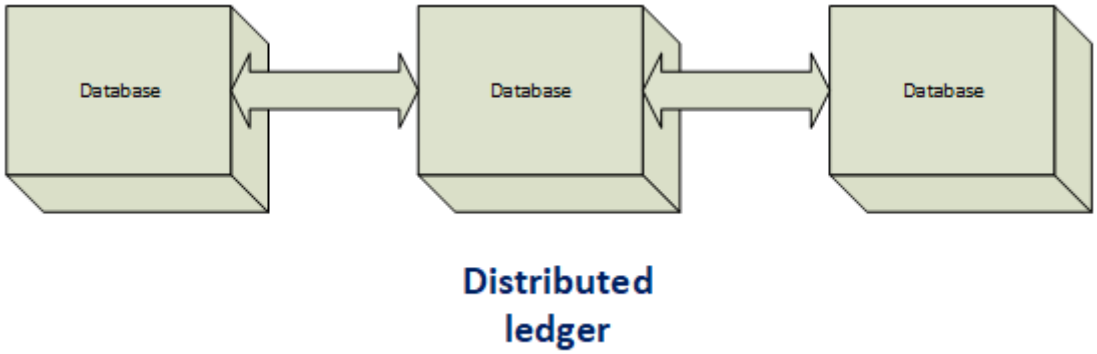
Fig. 17 Infrastructure of Smart Meter Integrated in Smart Grid

11.0 Block Chain Wallet Integration:

The calculation of the energy is performed by the smart meter. The tariff of the energy is adjusted by the service provider and it is automatically updated by the system admin connected to database. It will support many types of the crypto currencies like Ethereum, Bitcoin, Litecoin etc. Block chain technology originated from the cryptocurrency Bitcoin. It is a data structure architecture kept consistent by 'blocks' stored and maintained by every device connected to the block chain network. These 'blocks' are permanent time-stamped transaction records where each block links to the preceding block to create a ledger, allowing users to track and verify all submissions to the system. The integration of the block chain technology will enable the user to pay the bill easily with safety

and security ensured by the SSL. There is also a facility for the user to pay the bill through conventional payment methods like Credit Card, scratch cards, etc. Figure. 17 shows the complete process of the bill generation and the integrated block chain technology.

Block chain is collaborative with the ledger technology. These are simplest form of the database updated individually by each participant. This consists of the network and each individual represents as a simplest node. Every single node process the transaction and saved to the central database. The basic structure of the block chain is given below.



Once there is this consensus, the distributed ledger has been updated, and all nodes maintain their own identical copy of the ledger. This architecture allows for a new dexterity as a system of record that goes beyond being a simple database. This provides the secure and new kind of relationship in digital world to perform the transactions. Every single node has its own data, hash and hash of the previous block to record the chain. The data contains the calculated bill, ID number and even the location to provide the more security and reliability.

12.0 Conclusion:

The project is implemented to provide the renewable energy to the Africa. This includes the integration of the solar PV and smart grid to manipulate then bidirectional flow of the energy in KWh. The proposed design is calculated and simulated to analyse the characteristics. The inclusion of the lipo batteries also provides the energy in the night, this assures the 24 hours supply of the energy. The project have two models based on the solar park and top roof of the houses. The smart meter along with the IOT calculates the bill and saves the data into the server. To facilitate the user, block chain and other conventional payment methods are integrated into the design.

13 References

Gupta, V. (2017). Investigate the effect of dust deposition on the performance of solar PV module using LABVIEW based data logger. *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)*.

Jain, D. (2016). Anti-hebbian control algorithm for three-phase inverter in grid connected solar PV system. *2016 IEEE 7th Power India International Conference (PIICON)*.

Jamil, E. (2017). Dynamic modeling of regulated solar PV-wind hybrid system for off-grid applications. *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*.

Mathew, M. (2017). Analysis of a grid connected solar photovoltaic system with different PV technologies. *2017 IEEE International Conference on Circuits and Systems (ICCS)*.

Mathew, M. (2017). Analysis of a grid connected solar photovoltaic system with different PV technologies. *2017 IEEE International Conference on Circuits and Systems (ICCS)*.

Mohod, S. B. (2017). Hybrid power system with integration of wind, battery and solar PV system. *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)*.

Pradhan, S. (2017). A Digital Disturbance Estimator (DDE) for Multi-objective Grid Connected Solar PV Based Distributed Generating System. *IEEE Transactions on Industry Applications (Early Access)*.

Roy, J. (2017). A hybrid 9-level inverter with minimum number of switches for single phase grid connected solar PV system. *2017 IEEE 44th Photovoltaic Specialist Conference (PVSC)*.

Roy, P. (2017). Artificial neural fuzzy inference system based implementation of SVPWM for current control of grid connected solar PV system. *2017 Innovations in Power and Advanced Computing Technologies (i-PACT)*.

Sultan, H. M. (2018). Site selection of large-scale grid-connected solar PV system in Egypt. *2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*.

Sunny, A. C. (2017). SVPWM based decoupled control of active and reactive power for single stage grid connected solar PV system. *2016 IEEE 7th Power India International Conference (PIICON)*.