Power Management System for a Libyan Distribution Network to Meet Future Demand

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Abstract— **The continuation of increasing the power demand in Libya leads to raise the voltage regulation issues especially in distribution networks. This requires integrating more distributed generators (DGs) into distribution networks to meet such demand. However, operating several DGs into distribution networks raises stability, power management and voltage regulation challenges in Libyan power systems. This is due to the confliction of operation between the new integrated DGs and the existing equipments such as On Load Tap Changes Transformers (OLTCT). This paper introduces a potential solution to operate additional DG with existing OLTCT using Power Management System (PMS) supervision to overcome such challenges. The PMS controller works to supervise controllers of existing OLTCT and controllers of Automatic voltage regulator (AVR) and Governor (GOV) for additional DG to avoid the voltage regulation issue and to meet future demand.**

Index Terms: **Voltage regulation ; distribution netwok; power system managment;on load time changer;future demand**

I. INTRODUCTION

The increasing demand in Libya results in growing issues associated with stability, power management and voltage regulation in Libyan power systems [1,2]. General Electric Company in Libya has prepared a number of investigations to study the possibility of integrating additional DGs into distribution networks to meet future demand and to avoid the concerns that caused by operating several additional DGs with existing equipments[1,2]. The annual power demand in Libya is increasing significantly by 6 – 8 % of total current demand [1,2]. Therefore, the demand in Libya was 5.8GW by 2010 and it is expected to reach 9GW by 2020[2]. This paper examines the appropriate location of connecting additional DG into a real 11kV Libyan distribution network in order to eliminate stability, power management and voltage regulation issues occur in the network, especially at the peak and future demands. Moreover, it introduces a new method to operate a new additional DG with existing OLTCT using PMS controller to maintain voltage level within required limits. The PMS controller is operated to supervise the controller of existing OLTCT and controllers of AVR and GOV for new additional DG to maintain voltage level within the accepted range ±6% and to meet future demand [2,3].

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II. NETWORK CASE STUDY

An investigation of the control of the active and reactive power flow in the considered network is achieved by using a real Libyan case study network as shown in Figure 1. The main reason of developing this specific network for this study is to investigate how much power can be delivered through this network to regulate the voltage at range of ±6% when future demand is considered. The 11kV Libyan distribution network was modeled by Matlab SimPower software using the real parameters of each component of the network. The network consists of 8 feeders, two 30kV/11kV transformers and 21.2km of overhead lines and underground cables. The Y-Y connection, primary and secondary circuits are in phase; i.e., there are no phase angle displacements and the phase-to-neutral voltage is only 57.7% of the phase-to phase voltage [4,5].

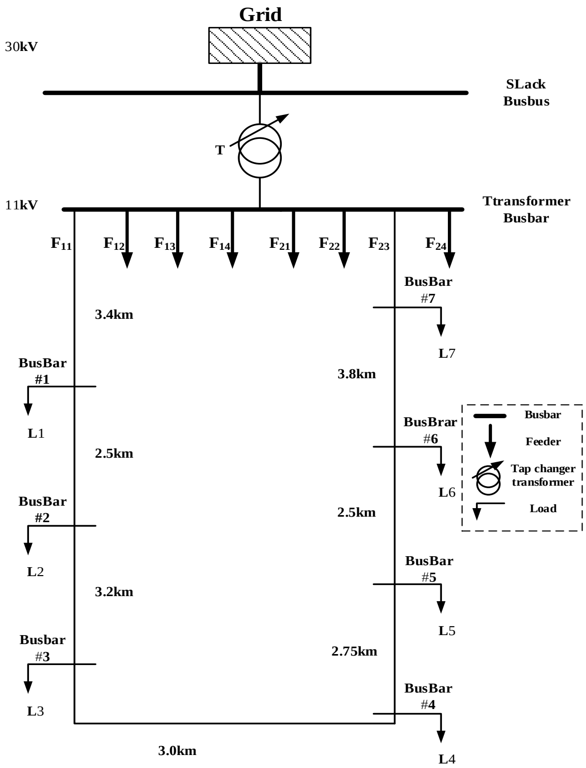

Figure1. The 11kV Libyan Distribution Network

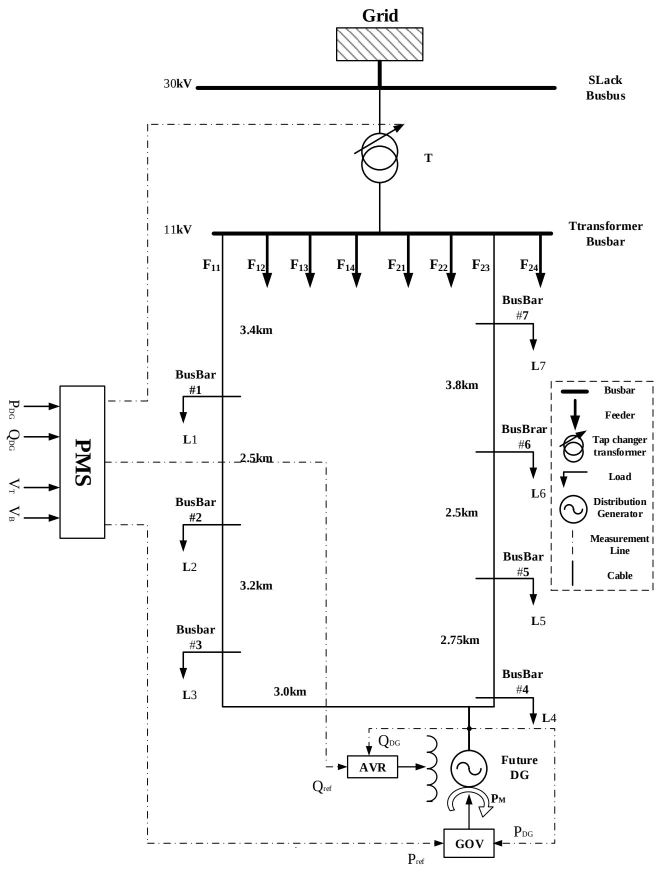

Figure2. The11kV Libyan Distribution Network with DG Connection

III. VOLTAGE CHANGES AT VARIABLE DEMANDS

A significant study has been achieved in this work to investigate the voltage level changes in the 11kV Libyan distribution network in terms of finding out the suitable location to connect additional DG without causing any voltage regulation issues. The future demand for 10 years has calculated based on increasing 8% of current demand per year [2,3]. Table 2 shows the voltage changes of the 11kV Libyan distribution network when future demand is considered. It can be seen that the highest voltage drop occurred at busbar 4 and it was 0.927 pu at future demand 36 MVA at power factor (0.9 lagging PF).

Table 1. Voltage Changes in the Network when Future Demand is Considered with/without Connecting a DG.

Future Demand	DG	Busbar voltage (pu)								
		Slack Bus	Trans Bus	Bus #1	Bus #2	Bus #3	Bus #4	Bus #5	Bus #6	Bus #7
36.18 MVA	Without DG	1	0.994	0.960	0.942	0.929	0.927	0.936	0.954	0.994
	With DG= 2.612MW	1	0.996	0.965	0.949	0.940	0.940	0.945	0.961	0.996

Based on that, the additional DG could be connected to the network to enhance the voltage performance to maintain voltage within required ±6%. Therefore, the DG has been connected at Busbar 4,where highest voltage drop has occurred. The maximum and minimum power, which can be injected from the additional DG, has been investigated in terms of maintaining the system stable. According to the investigation, the maximum power can be delivered from the DG was 2.612MVA at 0.9 lagging PF, when future demand is considered, to sustain the system stable.

IV. IMPLEMENTATION OF AUTONOMOUS CONTROL SYSTEMS USING PMS CONTROLLER

There are two types of control systems can be implemented in the distribution networks: autonomous control method and remote control method. In this work, an autonomous control system was used because of the possibility of reducing costs compared with remote controlled systems, as the latter requires additional devices to link the power system equipment with the control room [2]. The main reason of developing a network for this work is the investigation using the PMS to control the voltage level in 11kV Libyan distribution networks, based on the existing OLTCT and future additional DG. The PMS objective is to maintain the voltage of the 11 kV busbars within the limit (±0.06 pu) from the voltage level at slack busbar (1pu), and to meet the future demand using additional DG.

Thus, the PMS controller could be designed to supervise the OLTCT controller and the additional DG to meet future requirements, also to avoid the operational conflictions between the OLTCT and DG in order to keep the system stable in all conditions. The benefit of implementing the PMS at the distribution networks is reducing the capital cost of additional equipment, such as FACTS device, shun capacitors and regulator devices. These equipments would be used for distribution networks to maintain voltage level within required limit (±6%) especially at future demand [2,3,6]. Therefore, the study needs to develop a controller system for OLTCT to keep the voltage within the accepted limit at transformer busbar. Moreover, it needs to develop AVR controller and GOV controller for DG as a synchronous generator. After that, PMS controller needs to be developed to supervise all controllers in the system to achieve the main target of this study.

V. MODELLING OF THE ON LOAD-TAP CHANGER TRANSFORMER CONTROL SYSTEMS

Recalling that the aim of the tap changer transformer controller is to regulate the voltage in the distribution network, the tap-changing steps move up and down to adjust the secondary voltage of the transformer. The change in tap position was carried out in discrete steps with each beginning at 0.0125% of the normal ratio according to the transformer specifications that used in this real network. The function below was programmed in C++ and expressed mathematically for the controller.

$$f_{controller} = \begin{cases} 1 & V_{in} < -0.01 \\ 0 & -0 < V_{in} < 0 \\ -1 & V_{in} > 0.01 \end{cases}$$

The control system will be operated whether the error is greater than a bandwidth of 1% tolerance band or less than a of -1% tolerance band in order to maintain the voltage in the distribution network within the specified limit [6]. Thus, the control system works if the error is greater than a bandwidth of 1% tolerance band, then the tap position moves down one step. Whereas, if the error is less than -1% tolerance band, then the tap position moves up one step in order to maintain the voltage in the distribution network within ±0.06 pu. The control system of the tap changer transformer begins to work after 30 seconds and once the tap position is set, it holds for 10 seconds before the next change of tap position takes place [3]. The number of steps that could be made is ± 16 steps [1, 3]. Figure 3 shows the block diagram of the whole controller system for tap changer transformer.

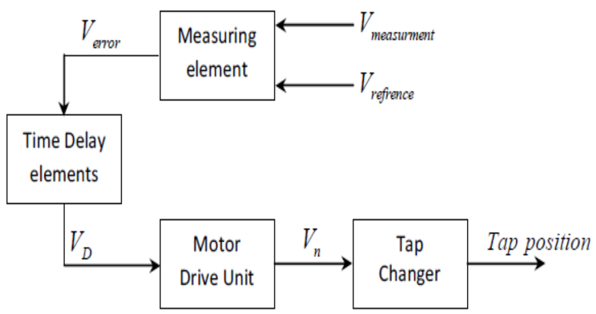

Figure3. The Block Diagram of the Controller for Tap Changer Transformer

VI. SYNCHRONOUS GENERATOR (DG) MODEL

Before modeling the synchronous generator, it is important to understand the capacity curves of this generator. In this study, the synchronous generator is implemented because it can operate independently or in synchronization with the network. Most distribution-scale generators are salient-pole machines with four or six poles driven by 1800- or 1200-rpm. The majority of the DGs run at nearly unity power factor. Furthermore, the Synchronous generators can be run at leading or lagging power factors and can operate as a voltage controller [8]. The stator and rotor heat limits, together with any external limits on any synchronous generator, can be expressed with a graphical form by a generator capability diagram as shown in figure 4. The capability diagram is a plot of complex power S=P+JQ. It is derived from the phasor diagram of the generator, assuming terminal voltage is constant at the machine's rated voltage [8]. Figure 4 shows the curve of P and Q for a synchronous generator.

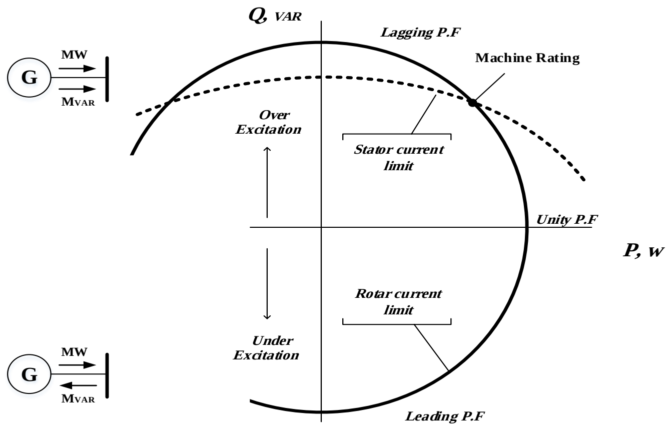

Figure 4. Curves of P and Q for a Synchronous Generator

A. Generator's GOV model

The governor (GOV) system consists of control and actuating equipment for adjusting the flow of steam through the turbine. This is for starting and stopping the unit, and for regulating the speed and output power of the generator. The governor system includes set point and speed sensing equipment, power and actuator position, compensation circuits, and hydraulic power actuators, which converts governor control signals to mechanical movement for the wicket gates [9]. Most modern governors use electronic means to sense speed changes. The torque supplied by the prime mover is adjusted by a governor valve, as shown in Figure 5. This could increases or decreases the steam flow. However, for a hydro turbine, it adjusts the water flow. This main valve can be operated manually or as a general practice, by an automated control system. The automatic governor system includes some devices that continually monitor the generator frequency. Any change from the set point (e.g., 3600 rpm) is translated into a signal to the main valve to open or close by an appropriate amount. Alternatively, a generator may be operated at a fixed level of power output, which would typically correspond to its maximum load. In this case, the generator is said to operate (on the load limit) [5].

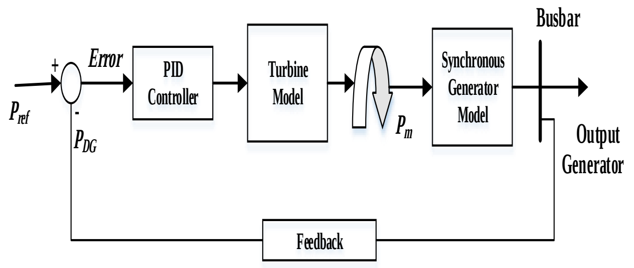

Figure 5. Generator GOV Model

B. Generator AVR model

It is well know that, one of the major functions of excitation system is to regulate the voltage of the generator terminal. The excitation of the generator can be adjusted using an AVR system which will run continuously to adjust the excitation of the generator, and in turn, influence the terminal voltage and reactive power exchanged with the network. The function of the AVR in this study is to keep the terminal voltage at 11 kV equal to the reference value (V_{ref}). Therefore, the reactive power output from the generator is changed in line with the terminal voltage of 11 kV. The approach of the AVR model was taken from [3], which was modeled according to IEEE type 2 [9,10]. Figure 6 exhibits the AVR model; all the parameters of the model are given in [2].

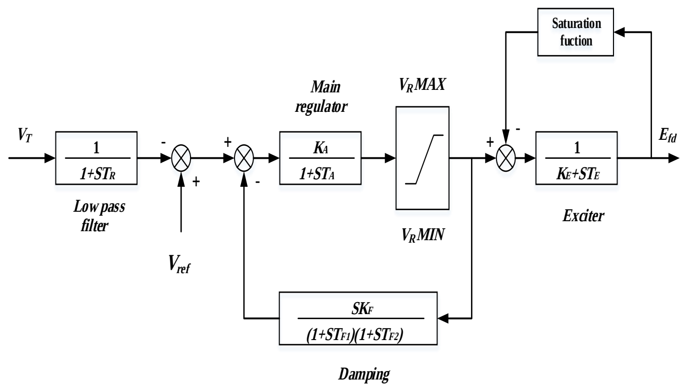

Figure 6. AVR Modeled Based on IEEE Type 2

VII. CONTROL STRATEGY

The control strategy in this work is focusing on the possibility of integrating the additional DG with the network to meet future requirements. This is carried out using an autonomous control system based on a PMS controller. Furthermore, this control strategy depends on providing reference values Q_{ref} and P_{ref} to the AVR and GOV to manage the active and reactive output powers from the DG within generator load limit. The AVR and GOV of the DG have a constant settling time of 10 seconds to be able to start operating. The active and reactive output powers are changing as the demand changes in order to control the voltage level of generator busbar within the required limit. The DG generates the minimum limit of power 2MVA at 0.98 lagging, when the voltage level of generator busbar within the limits of ±1%. This means that OLTCT has the ability to maintain voltage within required limit by keep the voltage of transformer basbar within ±1% from the reference voltage. However, once the OLTCT cannot overcome the voltage drop issues in the network, the output power of DG increases until the maximum limit 2.66MVA at 0.98 lagging. This was to meet the future demand and to keep the voltage level at the required limits ±6% in the network.

A control loop would be required in the PMS to provide Q_{ref} and P_{ref} to the AVR and GOV in order to obtain the desired power from the DG. The amount of the required powers Q_{ref} and P_{ref} are compared with the values of measured powers Q_{DG} and P_{DG} from the 11 kV network. The output power controller applies PID algorithms to eliminate any steady state error. PID controller provides the P_m for the mechanical turbine and V_{ref} for the generator AVR based on the power changes of the DG busbar as shown in Figure 7. Moreover, the PMS controller determines the tap position of the transformer during operation. It also requires a third control loop to manage tap changes during operation as shown in Figure 8. The control loop starts to work after 60 seconds from the operation [2,10,11]. The measured voltage is obtained from the secondary side VT of the 11 kV transformers, and then compared with V_{ref}. The obtained error is processed through the control system to evaluate whether it is within the required limits or not. Thereafter, the decision is taken for the tap position to move a positive or negative direction or to stay in the same position.

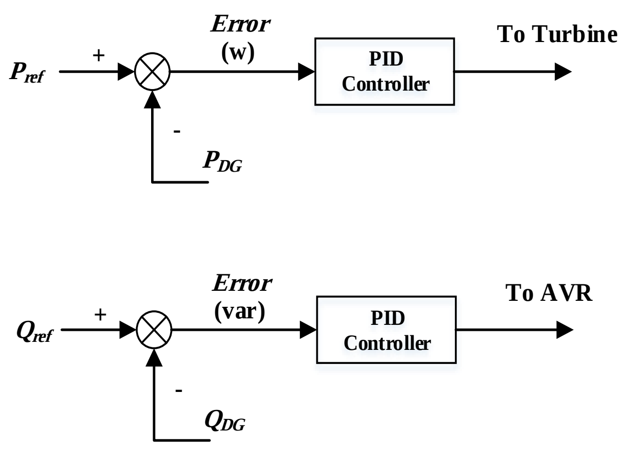

Figure 7. The PMS Controller Determines the Tap Position of the Transformer During Operations

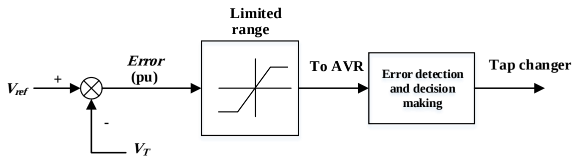

Figure 8. Third Control Loop to Manage Tap Changes During Operations in PMS Controller

VIII. RESULTS AND DISCUSSION OF SIMULATION

The voltage level in the 11kV Libyan distribution network drops to less than 0.94 pu at busbar #3, busbar #4 and busbar #5 at future demand 36MVA. Figure 9 shows the voltage behaviour in the 11kV Libyan distribution network with the PMS controller. Economic feasibility, the DG runs at the present time with 1.96 MW, 0.39 MVAR at power factor 0.98 lagging to contribute of supplying the loads, to reduce the power loss in the network and to keep system stability for the system.

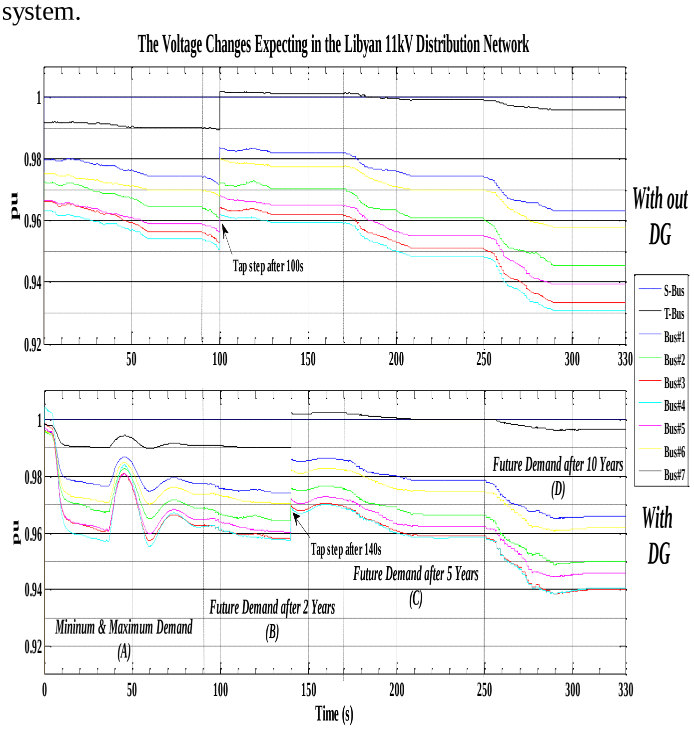

Figure 9. The Comparison for Voltage Changes in the 11kV Libyan Distribution Network with and without DG

As an evident from Figure 9, the DG takes 10 seconds to synchronize with the system network. The main target of implementing the PMS controller with the 11 kV distribution network is its ability to control the active and reactive output power from the DG and to control the transformer tap to keep the voltage within the required limit ±6% of whole network. At variable demands (20 MVA to 36MVA), the tap transformer stepped up when the voltage level of transformer busbar drops to less than 0.99 pu at 140 second as shown in Figure 9 at case B. In case D, the voltage level drops to less than 0.94 pu at busbar #3, busbar #4 and busbar #5. In the same time, the OLTCT could not move to solve this issue. This may be due to the error of voltage changes in bandwidth for OLTCT controller within limits ±1%. Therefore, the PMS changes Q_{ref} and P_{ref} for AVR and GOV controllers to increase output power (P and Q) of DG from 1.96 MW and 0.39 MVAR to 2.6 MW and 0.52 MVAR to retain the voltage within the limits (±6%) and to meet future demand 36MVA .

IX. CONCLUSION

Changes of the voltage level in the 11kV Libyan distribution network evaluate the future demand after 10 years, in order to find out the existing OLTCT in the network which can maintain the voltage within the limit ±6%. This study proves that the existing OLTCT is not able to maintain the voltage level within the limit ±6% in the network at future demand (36MVA). Therefore, in order to maintain the stability and to meet future demand; the additional DG is connected at the highest voltage drops in network. These occurred at busbars 3, 4 and 5. The DG generates 2MVA with 0.98 lagging at the current demand and the OLTCT can maintain the voltage within the limits. The amount of generating power from the DG reaches to the maximum limit 2.66MVA with 0.98 lagging at future demand. The PMS controller is implemented to supervise the DG and the existing OLTCT for all conditions . Besides, it can avoid any operation confliction between them and to eliminate any unnecessary operation of the OLTCT. In summary, these results show that PMS has the opportunity to meet the future requirements for the Libya power systems.

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